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**Infrastructure Development**

**Govt. offers relaxed norms for construction companies**

The Union government has offered relaxed norms for construction companies engaged in the construction of road infrastructure, real estate, stadium, warehousing, oil & gas exploration and hospitality sectors. It aims to increase the number of eligible contractors as the government wants to bid out more road projects to improve infrastructure and boost economic activities.

**CapitaLand plans ₹450-cr warehousing space in NCR**

The Singapore-based CapitaLand is negotiating to develop 3-mn sf of warehousing space at Sohna near Gurgaon. The company is in discussions with Mayar Group, which owns a 100-acre land parcel in Sohna. It will be a joint venture where foreign fund will develop the project involving an investment of ₹450 crore.

**Centre & States heighten infra spending in 2nd quarter**

Central and State governments have increased the pace of tendering and awarding new projects in segments like roads, real estate, community services, hospitals, irrigation, tourism and water supply treatment. Project monitoring agency, Project Today, informed that in September quarter, there was a 146% jump in infra spending by the states and a 67% increase in public and private sector tenders as against June quarter. Centre has separately announced new projects worth ₹54,339 crore in the same quarter, a sequential increase of 93%.

**DMRC plans commercial hub in east Delhi**

Delhi’s first transport-oriented development (TOD) project – East Delhi Hub, will come up near the Delhi Metro interchange facilities at Anand Vihar and Karkardooma in East Delhi. DMRC has decided to offer over 9.500 square metres commercial space at Karkardooma Pink Line station on first, second and third floors and it will be dedicated to retail, organized commercial space, offices and banks.

**TVS Supply Chain unveils ₹1,100-cr warehousing space**

TVS Supply Chain Solutions has planned to launch warehousing infrastructure on the outskirts of large industrial clusters such as Chennai, Pune and other cities involving an investment of ₹1,100 crore. The UK government’s investment arm CDC is injecting ₹369 crore and the work is all set to start.

**PNC Infratech gets LOA for ₹289-cr water infra contract**

PNC Infratech has announced the receipt LOA in a joint venture with SPML Infra for the construction of Haraulpur Group of Villages Water Supply Scheme (Surface Water) and Electric/Solar based Piped Ground Water Supply Scheme in Hamirpur District of UP. The contract, awarded by the State Water & Sanitation Mission, Namami Gange and Rural Water Supply Department of UP, involves the construction, operation and maintenance of the supply lines for 10 years at a cost of ₹289.83 crore.

**DJB clears mega sewage project worth ₹479-cr**

The Delhi Jal Board has cleared the sewage project worth ₹479 crore for building sewage network in Kirari belt of the national capital. The project will cover over 7.25 lakh residents across 114 unauthorized colonies and six villages. The completion period is three years.

**Dr. N. Subramanian elected as Fellow of the Indian National Academy of Engineering**

Dr. N. Subramanian, a well-known consultant, author and mentor, and Lifetime Achievement Award Winner, has been elected as a Fellow of the prestigious Indian National Academy of Engineering (INAE), effective November 1, 2020. The Academy honours Indian and foreign nationals who are elected by peer committees in recognition of their achievements (in the field of Engineering and Technology) which are of exceptional merit and have demonstrated distinctive know-how and expertise. Election to the INAE is among the highest professional distinctions accorded to an engineer. Up to 50 Fellows from Academia, R&D, and Industry are elected every year and the total number of Fellows at any one time does not exceed 1000. Dr. Subramanian regularly writes for NBM&CW and it gives us immense pleasure to facilitate him on this momentous occasion.
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MoRTH targets 34,800-km highways under B’mala
MoRTH has till date built 2,921 km of highways under the Bharatmala Pariyojana program and envisaged to build 34,800 km of roads at a cost of about ₹5,35,000 crore under it. A total number of 322 projects with 12,413 km of length have been awarded under the Program till August 2020 and 2,921 km has been constructed till the same date. Of the 34,500 km of highways approved under the Program, 10,000 km pertain to residual highway stretches under NHDP.

Welspun gets go ahead for ₹2,005-cr NH project
NHAI has given a go-ahead signal to the Welspun Enterprises to start work on the four-laning of Sattanathapuram-Nagapattinam highway section in Tamil Nadu at a cost of ₹2,005 crore. The authority has accorded the approval for appointed date with four-lane road and four-lane structures as against four-lane road and six-lane structures specified in the concession agreement.

MoRTH to start construction of ₹35,000-cr Delhi-Katra e-way
MoRTH is all set to start the construction work on the four-lane Delhi-Amritsar-Katra expressway involving an investment of ₹35,000 crore with a provision to be expanded to six-lane. Union transport minister, Nitin Gadkari, informed that by October 2023, people can travel by road from Delhi to Katra (Maa Vaishno Devi) via Amritsar in less than seven hours.

Haryana gets ₹1,300-cr Karnal bypass project
The Haryana government has informed that NHAI has approved the Karnal Eastern bypass road project involving an investment of ₹1,300 crore. The project, which aims at decongesting the Karnal city, will be 35 km. It will start from GT Road, covering the area between Madhuban and Kutel in Karnal, and will connect Jhanjari village while easing the connectivity of nearby villages as well.

NHAI agrees to NHBF’s suggestions on dispute resolution
To resolve issues and increase the pace of constructing highway projects, NHAI has agreed to most of the suggestions made by the National Highways Builders Federation (NHBF) related to project delivery. The suggestions included COVID-19 relief, bidding process, contract management, old & new Model EPC agreements, improvement of concession agreement of Hybrid Annuity Model (HAM), improvement of concession agreement based on BOT (Toll) and project preparation.

MoRTH launches two road projects in Andhra Pradesh
Union Transport Minister has laid the foundation stones for two road projects as a part of NH-16, a 30-km long 6-lane bypass road, from Chinna Avutapalli to Gollapudi. The projects, bagged by Megha Engineering, will drastically reduce the distance between Hyderabad – Kokilata – Chennai. Another road project includes NH-71 between Nayudupeta and Renigunta route, a single lane road facing frequent traffic jams.

KNR Palani Infra gets timelines for ₹920-cr road project
KNR Palani Infra has got the appointed date of 05 October 2020 from NHAI for the four-laning of Oddanchatram - Madathukulam section of NH - 209 (New NH-83) (Design ch. Km 29.000 to km. 74.380) under the Bharatmala Pariyojana Phase - I on HAM model. The bid project cost is ₹920 crore.
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L&T sets to win 237-km major portion of HSRC corridor

Larsen & Toubro has emerged as the lowest bidder for a major part of the Ahmedabad-Mumbai bullet train project, with a bid of ₹24,958 crore. NHSRCL informed that a total number of three bidders involving seven major infra builders had participated in the competitive bidding. The scope of work involves design and construction of 237 km long viaduct for 508-km Mumbai-Ahmedabad High-Speed Rail corridor being built with the financial help from Japan. The tender covers 47% of total alignment, between Vapi and Vadodara in Gujarat including four stations like Vapi, Billimora, Surat and Bharuch and Surat Depot, 24 river bridges and 30 road crossings.

YEIDA unveils ₹14,000-cr IGIA & Jewar Airports’ metro link

Yamuna Expressway Industrial Development Authority (YEIDA) has planned a direct metro link between Indira Gandhi International Airport and Jewar Airport costing ₹14,000 crore. Of the three proposals submitted by RITES, YEIDA selected a plan involving three stages including a 20-km line between Aerocity and Tughlakabad being built by DMRC; a 15-km extension from Tughlakabad to Noida Sector 142 on Aqua line; and a 35.6-km line between Knowledge Park and Jewar Airport.

MMRDA unveils ₹500-cr metro lines’ upgrades

In view of the state government’s decision to shift the Metro-3 car shed to Kanjurmarg from Aarey Colony in Mumbai, the underground line (Colaba-Bandra-Seepz) and Metro-6 (Swami Samarth Nagar-Vikhroli) line will be integrated before the proposed elevated Saki Vihar station of line 6. Metropolitan Commissioner MMRDA, RA Rajeev, informed that it will be a common elevated line with six stations up to the Kanjurmarg depot site.

Govt. plans parallel rail line beneath Zojila Pass in J&K

The Union government has planned a parallel rail line along all-weather tunnel beneath the Zojila pass in J&K. National Highway and Infrastructure Development Corporation has presented the proposal to transport ministry and the PMO has directed the agency to look into the option of integrating road and rail networks on this stretch.

ER hastens work on ₹6,600-cr high-speed rail corridor

Eastern Railway has started the groundwork for building infrastructure for a high-speed rail corridor between Kolkata and Delhi, which is aimed at curtailing travel time from 17 to 12 hours. The Railway authorities believe that 160 kmph high-speed rail corridor will be completed by 2022 at an estimated investment of ₹6,600 crore.

APMRCL starts work on ₹22,000-cr metro projects

Andhra Pradesh Metro Rail Corporation Limited (APMRCL) has started the groundwork for the construction of Vizag metro rail project for which the preparation of the detailed project report (DPR) is in full swing. Of the 140.11km-long metro project in Visakhapatnam, corridors for 79.91km are proposed for the development of a light metro rail system, and a modern tram line will come up in the remaining 60.2km corridors at a combined investment of ₹22,000 crore.

Kerala to get ₹63,941-cr High-Speed Rail Corridor

State PWD Minister, G Sudhakaran, informed that Kerala government has cleared the Thiruvananthapuram-Kasaragod high-speed rail corridor at a cost ₹63,941 crore and it will soon get the green signal from the Union government. The project will be built in a joint venture between Indian Railways and the Kerala Rail Development Corporation Limited (KRail). The State’s Cabinet has already given its approval to the detailed project report (DPR), submitted by the project implementing agency KRail.

CSMT station gets upgrade worth ₹1,642-cr

Union Railway Ministry informed that the Western Railway has launched the redevelopment of the Chhatrapati Shivaji Maharaj Terminus (CSMT) Railway Station in Mumbai at an investment of ₹1,642 crore and on completion it will separate arrival and departure with disabled-friendly facilities.

Gorakhpur gets 28-km long Light Metro Project

Expanding the metro network across cities in UP, the state government has cleared the Light Metro project for Gorakhpur. The project, which is to be completed by 2024, would span almost 28 km long with two elevated corridors where one elevated corridor would span 15.14 km comprising 14 stations, the other corridor would run 12.70 km and consist of 13 stations.

SAM India Builtwell wins ₹150-cr Kanpur Metro contract

The UP-Metro Rail Corporation Limited (UMPRCL) has issued a letter of acceptance (LoA) of ₹150.14 crore to SAM (India) Builtwell for carrying out civil work package (KNPCC-04) for Kanpur Metro Rail projects. The station and viaduct construction work on the priority section (IIT Kanpur - Motijheel) is being carried out by Afcons Infrastructure.
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KIIFB clears ₹289-cr for a bridge at Ponnani in Kerala

KIIFB has cleared ₹289 crore funds for the construction of a bridge, which will come up across the Bharathappuzha connecting Ponnani harbour with Padinjarekkara. The hanging bridge has been modeled on the lines of the Howrah Bridge in Kolkata. The one km-long sea bridge will pass over the estuary where the Bharathappuzha opens out into the Arabian Sea.

NHAI plans 3-grade separators in J&K

The central government has approved ₹574.16 crore annual plan 2020-21 for national highway works in J&K. After which, the NHAI took over the construction of three-grade separators along the bypass on NH-44. The major works of the project include the construction of 3.23 km three flyovers in Srinagar on NH-44 at Bemina, Sanat Nagar and Nowgam costing ₹135 crore.

Megha Engineering bags ₹3,500-cr tunnel project

NHIDCL has awarded the work of a 14.1 km long tunnel to Hyderabad-based infrastructure major, Megha Engineering. The transport ministry had restructured the earlier alignment, which brought down the cost of the tunnel to ₹3,500 crore.

Tamil Nadu state highways department has launched the construction work on the elevated highway project along Avinashi Road. The 10.01km long elevated highway will connect Uppilipalayam to Goldwins at an investment of ₹1,621.3 crore. The state government has released ₹200 crore for the project, which is targeted to be completed within four years.

Sany India strengthens presence in Rajasthan; opens new dealership in Jodhpur

Sany India, a leading manufacturer of construction equipment, heavy machinery, and renewable energy solutions, has further strengthened its presence in Rajasthan by getting on board Jasraj Infra in Jodhpur, who will exclusively deal in sales, after-sales service, and spare parts business of Sany excavator’s product line. The dealer will provide service in several districts of Rajasthan, namely, Jodhpur, Bikaner, Jaisalmer, Barmer, Pali, and part of Jalore.

Said Dheeraj Panda, Director – Sales, Marketing, and Customer Support, Sany India, “We are delighted to welcome a new dealer into the Sany family. With the growing demand for our products, dealership expansion was the most prudent way to make inroads into untapped markets and gain customers’ confidence.”

AJAX Engineering plans new facility in Bangalore

AJAX engineering has acquired a 20-acre land parcel in Bangalore and will invest ₹100 crore to develop a new manufacturing facility there. The company is expecting greater demand for its equipment post lockdown and is likely to get orders from big government infrastructure projects and from the real estate developers in the residential segment. Jagadish Bhat, MD & CEO, informed that the company has acquired land from Karnataka Industrial Areas Development Board (KIADB) at ₹34 crore and will invest another ₹60-70 crore to develop the facility.
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Real Estate

Sunteck Realty has planned to acquire a 50-acre land parcel in Vasind, Mumbai to develop a residential project. The project will have a revenue potential of ₹1,250 crore. Kamal Khetan, Chairman and MD of Sunteck Realty informed that this second strategic acquisition amidst the pandemic complements the strategy to strengthen the brand presence.

M3M India, which acquired 25 acres of land in Gurugram for about ₹250 crore, has planned to develop housing project on the land parcel at Golf Course Extension Road in the satellite city. The company, which owns more than 2,000 acres of land parcel in Gurugram, is scouting for land parcels in Delhi-NCR for future development.

Shapoorji Pallonji's mid-income housing platform Joyville has decided to invest ₹1,200 crore to develop a new residential project in Pune. This is the fifth project of Joyville and second in Pune property market. The project ‘Joyville Hadapsar Annexe’ will be developed in phases, with the first one comprising 600 units and the total units in this project will be more than 2,700 with a price tag of ₹37.5 lakh upwards.

M3M plans 25-acre realty venture in Gurugram

M3M India, which acquired 25 acres of land in Gurugram for about ₹250 crore, has planned to develop housing project on the land parcel at Golf Course Extension Road in the satellite city. The company, which owns more than 2,000 acres of land parcel in Gurugram, is scouting for land parcels in Delhi-NCR for future development.

GBP Group plans ₹600-cr townships in Zirakpur

Given the emerging business avenues in the realty sector on the outskirts of Chandigarh, GBP Group has decided to invest ₹600 crore to develop a township in Zirakpur. In the new township, stretching across an area of 32 acres, the company will develop 700 flats, 400 plots and 750 commercial units.

Bhutani Infra unveils ₹5,000-cr realty projects

The Delhi-based commercial real estate player, Bhutani Infra has targeted to invest ₹5,000 crore in the next three years for developing three commercial real estate projects in Noida and Greater Noida and will deliver about 16 mn sq ft. The company plans to sell 75% of the area and give 25% space on lease. It is currently developing three commercial projects -- Bhutani Alphathum, Bhutani Grandthum and Bhutani Cyberthum in Noida and Greater Noida.

Birla Estates plans ₹550-cr realty project in Gurugram

Birla Estates has decided to invest ₹550 crore to develop 700 units of independent floors and high-rise buildings in Gurugram. The company has tied up with the Delhi-based realtor Anant Raj to develop residential township on an area of 73-acre land parcel.

Lodha Group floats luxury housing scheme

Lodha Group has announced a new category of property, a luxury gated community of villas on the outskirts of Mumbai in Thane. Shaishav Dharia, Business CEO, Township and Annuity Assets informed that the project, which has been designed by Hafeez Contractor, is located just 15 minutes away from Viviana Mall on the Mumbai-Nashik highway offering home seekers independent home on their own land.

Launch of EECMAI - Elevator & Escalator Component Manufacturers’ Association of India

Through the grim period of the pandemic, the component manufacturing companies of India - the world’s fastest growing elevator market - have taken a much-needed progressive step to establish the Elevator & Escalator Component Manufacturers’ Association of India (EECMAI).

EECMAI, with the objective of making India “Atmanirbhar” (self-reliant) and a dependable global market hub for elevators and escalators (E&E), was registered with the Ministry of Corporate Affairs on September 10th, 2020. The first group of EECMAI members met on September 19th, 2020 and unanimously elected the inaugural Management Committee comprising of President: Suraj Thodimarath (Wittur), Vice President: Hiren Panchal (Apson), Secretary: Kumara Swamy (Monteferro), Joint Secretary: Nayan Movaliya (Tectronics), Treasurer: Abey George (Fermator), Director-Ethics: Ashok Subhedar (DSA Controls).

While taking charge as the first president of EECMAI, Suraj Thodimarath stated “Amongst all the nations in the world, India is best placed to emerge as an alternate global powerhouse for the manufacturing of E&E components that comply with the international standards of safety and performance. The timing of the formation of EECMAI is fortuitous in the sense that it coincides with the attempt of global businesses to de-risk their supply chain from single country dependencies. EECMAI will drive initiatives that will help the Indian E&E industry to expand beyond India and become an integral part of the international supply chain. EECMAI will establish relationships with other E&E Associations and appropriate Government agencies to promote and protect the interests of the users and the industry.”
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Several PSUs will be requiring capital infusions in the form of fresh equity capital to survive and cover the losses incurred due to Covid-19. As the central government’s finances are stretched, it is not in a position to provide the requisite capital to the PSUs. It is here that REITs can pitch in and the government can raise funds for the PSUs without losing the ownership control at the company level.

According to Shishir Baijal, Chairman, Knight Frank India, in view of the extraordinary interest shown by the foreign investors, even during the pandemic, it’s an opportune time for the government to use this appetite for rent-yielding office assets for raising funds for the PSUs.

It may be mentioned that the central government owns a large number of PSUs, some of which are listed while others are unlisted, and under its sole ownership. Among the listed entities, the government has a controlling stake in a majority of the PSUs.

As per the REIT plan prepared by Knight Frank, the office buildings owned by the PSUs can be transferred to a separate SPV. This transfer can be done through a sale and lease back arrangement with the SPV. The PSU can sign a long-term lease of 20-25 years with pre-defined rental escalations, with room for making the rents to market rate every 8-10 years. The Centre would float/sponsor a REIT which would take control of the SPVs. The amount owed to PSUs due to the sale and lease back, can be transferred in the form of a proportionate equity stake in the REIT. The government can list this REIT on the stock market and raise the necessary funds for the PSUs. In case of financially strong PSUs, a part of the money raised through the REITs can also flow back to the government in the form of dividends.

This fund-sourcing model ensures that there is no change in ownership status at the company level and the employees can continue to work from the same premises. This arrangement will, however, turn the PSU from an asset owner to a tenant of the building on its balance sheet.

Though the operating cost of the PSUs would go up to the tune of rent outgo every year, yet the PSUs will get balance sheet headroom, which will help reduce their financial leverage. PSUs will get the advantage of an alternate source of raising funds at a competitive cost, compared to debt.

This REIT opportunity for PSUs, according to Knight Frank, amounts to ₹1.2 trillion or ₹120 lakh crore, based on book value of office assets of 45 listed PSUs. However, if the value of the office buildings of unlisted PSUs and smaller listed PSUs is taken into account, the actual REIT opportunity will be far bigger.

The PSU REITs can be capitalized at 6.4% yield - the trading yield of the two currently operational REITs. REITs can help PSUs raise funds at much lower rates, compared to bonds and NCDs. Moreover, REITs have the inherent advantage of having real estate assets as underlying, and REITs for PSUs will offer value propositions to investors.

REITs are a stable product and have a proven track record of offering stable returns across business cycles globally and are used as a portfolio diversification tool. The dividends from REITs in India are exempt for tax purposes, provided the REIT adopts the old rate of corporate tax. Further, REITs provide scope for capital appreciation and any gain through capital appreciation is taxed similar to debt.

There are several mutual funds, pension funds and insurance funds which invest a significant percentage of their assets under management in G-Secs, bonds/NCDS floated by sovereign entities. REITs can serve as a credible alternative for this set of investors. For retail investors, the government backed PSU REITs can serve as a credible alternative to sovereign backed saving schemes like PPF, NSC etc. REITs have an advantage of offering greater liquidity, compared to other instruments and can be sold at any time without any restrictions. Dividends are tax-free for REITs and they provide scope for capital appreciation.

A similar capital raising model can be used to monetize rent-yielding assets of Indian Railways, Metro Rail, Airport Authority, Bus Terminals etc who get monthly rent from occupiers of their premises. The money raised through this monetization model can be used for new infrastructure development.

The writer is Editor, PropTOQ real estate magazine
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Compaction Becoming More Advanced

Compacators are required to work on different types of terrains and within a very tight time schedule. Hence, the vital features required in compactors are higher levels of productivity with fewer numbers of passes, and right frequency settings. As the market becomes more competitive now, soil and tandem compactor manufacturers are coming up with new solutions like pneumatic tyred rollers and manufacturers are coming up with new products designed to measure, monitor, and control compaction and the stiffness value, and the HAMM Temperature Meter (available for asphalt) for measuring the asphalt temperature. It also includes the HAMC Navigator for measuring the number of passes.

Wirtgen India: Integrating Intelligent Systems

The WIRTGEN GROUP machines are integrated with intelligent compacting systems to ensure more uniform and consistent compaction with greater material density. Avinesh Ramesh Palagiri - MD & CEO – Wirtgen India, “To achieve the best compaction, the material temperature and the compaction measurement are most important, HAMM has developed an electronic tool called Hamm Compaction Quality (HCQ). It comprises several HAMM products designed to measure, monitor, document and control compaction and the compaction processes. These include the HAMM Compaction Meter (available for earthworks and asphalt) for determining the stiffness value, and the HAMM Temperature Meter (available for asphalt) for measuring the asphalt temperature. It also includes the HMQ Navigator for measuring the number of passes.

Palagiri informs that the HAMM compactors offer two amplitudes (high and low) and two frequencies (high and low), which are enough for the best compaction in almost all operating conditions across India. HAMM’s technical advancements in compaction equipment like the HMQ Navigator, HAMMTRONIC, and VO (Vibrations-Oscillation) machines, enable continuous compaction control, energy compensation for machine to work at set parameters, and avoid less or over-compaction. These features help in completing compaction at a faster rate and give high-quality results.

Good maneuverability in HAMM compactors is achieved through the company’s patented 3-point articulation joint. For minimizing passes and adjustment of amplitude and frequency, optimization of all the machine parameters is done through electronic machine management system HAMMTRONIC that monitors and controls the key functions. The opportunities offered by HAMMTRONIC include automatic adjustment of the diesel engine speed to meet the power requirements of the individual drives (driving & vibration). It controls start-up and braking and distributes the drive torque across the drum axle and/or rear wheels in accordance with real-time operating data (such as incline, driving speed & direction). HAMMTRONIC also controls the hydrostatic vibration drive and the various steering programmes (for DV+ series only), guaranteeing even and smooth movement of both the drums.

Wirtgen India has been using digital technology during the current Covid-19 scenario to hold internal and external meetings and for customer training programs. Says Palagiri, “Even during this crisis, we will continue to invest in R&D in order to bring innovations across all our product lines.”

JCB India: Monitoring Performance Closely & Constantly

“JCB compactors deliver best-in-class compaction performance; in fact, India is the global manufacturing hub for JCB compactors,” says Deepak Shetty, MD & Deputy CEO, JCB India. “For us, productivity is a combination of the product, its design and the reliable product support that follows. JCB has always been committed to ensure that the customers get the best performance and productivity while using JCB machines.”

He informs that the India-built JCB machines fully comply with the latest emissions and operating standards for foreign markets. Currently, JCB manufactures a wide range of compactors. In India, the company is offering three models: the VM760 which is a Tandem Roller, the VM116, a Soil Compactor, and the VM730 which is a smaller 3T category Tandem Roller.

JCB compactors produced in the company’s state-of-the-art facility in Pune, are being exported for the past few years. These Made in India machines are not only building infrastructure in India but are equally popular in the South Asia region and in countries such as Singapore and Thailand. JCB has also invested in setting up a Design Centre in India which works on Indian projects as well as for global markets.

The company has a strong focus on Digitisation and Innovation; JCB machines are enabled with JCB’s advanced Telematics Technology – Livelink, for Next Generation Asset Monitoring and Fleet Management. Says Shetty, “This technology benefits customers in better fleet and fuel management by enabling remote monitoring and management of their machines. JCB LiveLink incorporates GPS, Telecommunications, Machine Electronics and IoT, enabling the equipment to remain in contact with the owner, dealer and JCB at all times.” The ‘Livelink’ technology which JCB had introduced about five years ago, enables better site management and equipment utilisation, thereby improving the operational efficiency and cost-saving in the operations. Geo-fencing and Time-fencing have further increased the security of JCB machines. “Further, JCB’s InSiteCompaction system is an innovation which will disrupt the way compaction is carried out. It measures relative compaction density which is continuously displayed to the operator using a colour LCD screen. This helps the operator to avoid both excessive and lower than required compaction level with predetermined set values as reference. This helps save time and money by avoiding repeated compaction, increased mechanisation and the need for ongoing quality assurance would be key drivers for the Indian market to adapt to the Next Level GPS positioning enabled real-time compaction density measurement systems,” informs Shetty.

JCB compactors have optimised front and rear weight distribution, amplitude and frequency combinations. A high centrifugal force with a new balanced suspension system ensures the highest energy transfer, be it soil or asphalt application. The design of JCB’s vibratory system with a single-piece eccentric shaft and overturning weights is well proven; it

Modified drums and intelligent compaction are the new value engineered add-ons that promise higher productivity at a lower operating cost. However, the higher initial cost of these machines can be offset by enhanced post-sales support and services by the manufacturers to ensure their higher availability. P.P Basistha reports.
delivers excellent compaction performance for all applications. This also results in improved maneuverability as the vibratory drum remains stable (single jump) on compacted ground during vibration mode on level ground as well as on gradients. Higher energy transfer ensures minimum passes required to achieve the required compaction.

“While this design offers high level of performance, it also keeps it simple to operate through two amplitude settings to select from, based on the application. This vibration system keeps the design architecture simple for long life and ease of service. The focus has been to keep the equipment robust and high on productivity,” adds Shetty.

To ensure convenience in ordering parts, JCB has introduced the Mobile Parts application - a first in the industry. Through this, customers can order parts online. This also helps in monitoring the exact location of the consignment. “All JCB India machines are backed by after-sales service support through 700 outlets and over 60 dealers across India. The outlets are equipped with parts and trained manpower, thus ensuring that our customers are never far from professional product support. We have further developed an internal tool ‘Smart Serve’ which digitally supports service engineers and service jobs to improve machine efficiency and productivity, thereby improving customer profitability,” informs Shetty.

“After the lockdown, the months of April and May saw very little infrastructure development activity. However, we are seeing some green shoots in the months of July, August and September as the Road Building activity is slowly resuming. This is good news for the industry which was grappling with very little equipment utilization for a long time and we hope that the momentum continues.”

“We remain positive and hopeful for the future. As the thrust on infrastructure creation continues to be a priority for the government, we are optimistic of a strong recovery. Rural India, where we have a significant presence, is also set to emerge as the new growth driver for us in the coming days. An embodiment of the ‘Make in India’ and the ‘Aatmanirbhar’ programmes, our machines have been contributing to the building of world-class infrastructure in the country for over 40 years. Our five state-of-the art factories in Delhi-NCR, Pune and Jaipur operate to ‘One Global Quality,” adds Shetty.
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CASE India: Enjoying Brand Recall

CASE India offers asphalt and soil compactors for use in various kinds of earth layers. It has recently launched its new CASE 752EX asphalt compactor, which, according to Sandeep Mathur, India CE Brand Leader, Case India, is more compact and features excellent asphalt compaction and better visibility of the sprinklers. Operator comfort has been improved with optional sliding and rotating seats.

“CASE Construction’s latest range of soil compactors is also of robust design and equipped with the powerful FPT engine. Since our compactors have high maneuverability with a 15° drum oscillating angle, 37° steering angle, and a short steering radius, they can work at constricted sites with ease as the operator can handle the equipment smoothly and safely at the site. The compactors’ low steering effort reduces operator fatigue and matches the frequency and amplitude vibration of the soil for a smooth operation. They are also technically equipped to provide information on amplitude, frequency, and are also easy to transport. CASE 1110EX-D, for instance, has been given an air-conditioned cabin for operator comfort,” says Mathur.

He informs that Case India’s 1107 EX and 1110 EXPD soil compactors enjoy a strong brand recall. The 1107EX has best-in-class compaction force that ensures fewer passes for compaction, thereby saving the customer’s time and money. The amplitude and frequency settings are of the desired quality. The machine’s hydrostatic variable speed control ensures that it travels at the right speed for every type of soil, resulting in uniform compaction throughout the road stretch. The compactor also comes in the drum drive version for jobs that require compaction of gradients, and a pad foot version, which is recommended for compaction in clay or silt or for garbage compaction. The optional drum drive system features an additional high torque drive motor mounted on the front drum frame, resulting in excellent gradeability (36%) and optimized traction.

The 1110 EX-D has a closed HVAC cabin, a robust design, and an FPT engine of 110 hp. This compactor is suitable for heavier applications and good control results in good compaction of the sub-grade as well. Superior compaction is enabled through the thickest drums while the rotating operator seat and tilt-able steering give excellent front and rear drum/nozzle visibility, making the drive and compaction process easier, safer, and more efficient.
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Dynapac: Improving Machine Performance

Abhijit Som, MD, Dynapac Road Construction Equipment (member Fayat Road Equipment Division) informs that the company added 13-ton Soil Compactors during 2019. “The 13-ton soil compactor model CA385D features higher Static linear load 39 kg/cm & Centrifugal force of 300KN that offers greater depth of compaction. When compared with the 11-ton soil roller, it offers 35-40% more compaction performance. The machine had very encouraging acceptance in the Bharatmala project,” he says.

Abhijit informs that Dynapac India has incorporated a brand-new compaction control system on its soil rollers to measure the compaction degree and it can accurately show compaction at various grades. The company has also introduced a new Eccentric system that requires less starting torque, thereby reducing the machine load and improving fuel economy. This was implemented in all Dynapac rollers worldwide and was launched in India in 2019. “Our new Rhinos series of Soil Rollers have the Eccentric vibration system which is a patented technology. It will ensure lower maintenance cost of rollers and reduce the overall cost of operation for the end-users.”

The company’s Competence Center at Karlskrona in Sweden has also introduced a brand new SEISMIC roller concept that optimizes the roller vibration frequency based on the soil condition, to achieve faster and better compaction. “This was the result of many years of study by our Swedish design team and was achieved through a control system implemented on the Soil Rollers with an on-board CANBUS system built in Sweden,” informs Abhijit.

Dynapac’s DYNALINK - a machine uptime tool - helps run periodic maintenance as well as delivers information on the machine’s utilization to the owner and operator. “We are implementing a number of maintenance contracts while optimizing machine performance with onsite support,” says Abhijit.

LiuGong India: Focusing on Localization

LiuGong India, that offers 11 ton soil compactors, is making the products more cost competitive by bringing complete localization in their manufacturing. The machine is fitted with engines from Kirloskar, hydraulics from Bosch Rexroth, and their hydrostatic transmission makes them extremely reliable in their performance. Avers A Krishnakumar, President, LiuGong India. “The right level of amplitude and vibration combined with the right axle loads, helps our compactors deliver better compaction. In fact, due to their superior performance, we have made significant inroads in the compactor market, and are already enjoying a strong brand recall. Our marketing strategy is to promote our compactors as a packaged product, backed by their timely maintenance and parts support.”

LiuGong offers complete solutions for road construction and compactor is part of their range.
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Ammann India: Showcasing Design Competence

Ammann India is continuing to position its ARS 121, 11-ton soil compactors and its ARX 91, 9-ton asphalt compactors based on their ‘all-inclusive design competence’. Says Girish Dixit, General Manager R&D Division, Ammann India, “This encompasses competitive features for superior performance, lower cost of operation, easy access for maintenance, reliability, and safety in operation when working on hilly terrains and gradients. Our soil compactors have a robust four-bearing drum design that gives a uniform compaction force to achieve desired compaction, while other manufacturers are offering compactors with two-bearing drum design.”

He informs that uniform compaction results in a lesser number of passes which subsequently reduces the operating cost with lesser fuel consumption. The compactors are of compact design, with articulated maneuverability that requires lesser turning radius; better visibility for the operator makes the job safer; and ease of maintenance is enabled by higher drain out and replacement intervals of the drum oil, engine oil and filters. Both the asphalt and soil compactors are powered by Cummins and Ashok Leyland engines, respectively.

Ammann India is also promoting its 24-ton pneumatic tire rollers (PTRs) and Light compaction products which are imported from its plants in Czech Republic and Germany. Says Dixit, “The Pneumatic Tyre Roller is World’s famous multiple wheel compactor. Based on proven design, brings the highest value for the customers. Proven hydrodynamic propulsion systems, together with a simple and reliable Cummins electronic engine ensures high productivity and reliability. Easy machine control provides great comfort of operation.”

The pneumatic tyre roller AP 240 is the static roller that uses the deadweight and kneading effect of tyres to achieve the desired compaction results. AP 240 offers a wide ballasting range from 9.5 to 24 tons. Easy ballasting and un-ballasting provide flexibility to set up an exact wheel load as per the jobsite conditions.
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Larsen & Toubro: Make in India Initiative

According to Jaikumar Kamath, Head, Road Machinery Business, Larsen & Toubro, despite the market for compactors remaining contracted during 2019-20, L&T gained market share for its Compactors. The market size for Compactors in 2019-20 was 4500 machines and L&T garnered sizeable business, “We owe our improved sales to a strong brand recall and repeat orders from our customers who include rental companies, main and sub-contractors, and have remained loyal buyers even during these challenging times. We owe this to our well-crafted strategy of giving strong pre- and post-sales support so that our customers get the total lifecycle cost for their machines. This is an achievement considering that we entered the compactor market only five years ago.”

L&T manufactures 3-Ton and 10-Ton Tandem Compactors and 11-Ton soil compactors, besides the 24-ton Pneumatic Tyred Roller. Says Kamath, “The pneumatic tyred roller is a niche application product in road construction. Demand for this product, PTR, is still at a nascent stage in India, but we plan to popularize it, given its features and applicability.”

He informs that L&T compactors have been indigenously designed and have higher uptime at job sites. The compactors have a lower fuel consumption of about 5-10% as compared to competing brands. For superior performance, the engine power and the hydraulic system have been perfectly calibrated so that fuel consumption is optimized. The hydraulic system of the L&T compactors has also been validated to perform at high ambient temperatures, which are prevalent in many parts of India during the summer months. A feature of the machine is the longer hydraulic oil change intervals, and the higher capacity hydraulic oil coolers which are fitted in the L&T Compactors. The superior productivity of the L&T soil compactor L&T 1190 is due to 32 mm thickness of the drum shell which increases the drum weight. A heavier Drum vibrating improves compaction. The components on the L&T Compactors are all sourced from vendors of global repute. All these attributes provide a much lower total lifecycle costs of the compactors. This is the reason why in a short span of 4 years since the launch of L&T compactor, numbers have crossed 2000+. Many customers have a large fleet of L&T compactors. These machines are manufactured by L&T Construction Machinery Limited (LTCL - 100% fully owned subsidiary of L&T) at its state-of-the-art manufacturing set-up at Bengaluru. L&T has 30 dealers spread nationwide and has over 100 dealer outlets that render timely service and support to the machines. Says Kamath, “To make maintenance and operation more affordable for our customers, we provide them customized service kits that include all the parts needed for a particular service to be carried out.”
Action Construction Equipment: Engaging with Customers

ACE Tandem and Asphalt Compactors come in a 9-ton operating range and are powered by the fuel efficient KOEL 76 hp engine. The tandem roller has a unique amplitude setting which makes it a high performing product not only for asphalt application but also for soil compaction. Avers Adarsh Gautam, Head Sales & Product Support-Road Construction Equipment Division, ACE, “Our tandem rollers are the only rollers that provide adequate compaction in both asphalt and soil applications. Their frequency ranges from 30 Hz to 50 Hz, making them suitable for a wider range of applications. We are in the process of redesigning the tandem rollers with some new features which will bring more benefits to our customers. Currently, our ADD95 is giving complete solutions for all kinds of asphalt compaction. It has a rotating and sliding seat that helps the operator to easily view side and corner compaction work. In our Vibratory Roller range, we have an Intelligent Compaction system as an optional feature, along with adequate drum width for maximum surface coverage.”

The ACE team is engaging proactively with its customers and is providing them complete support and services. Gautam informs that the company has extended the warranty period of all their machines by three months due to their non-utilization during the lockdown period. ACE has also been educating its customers on safety and better upkeep of the machines, and conducting online service, safety, and maintenance training programs for its customers’ site staff. “Around 2500 people were trained on various aspects of our machines such as their operation, safety, maintenance, engine, hydraulics, transmission, tyres etc. We have provided this free of cost facility to our top clients like L&T, Tata Projects, GR Infra Projects, Shapoorji Pallonji, Kalpataru, Monte Carlo, Ashoka Buildcon, and BG Shirke, among others.”

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Report – Compactors
Continuous research and development related to the improvement of design of traditional structures, design of challenging structures, requirements for meeting the changing global prospective in terms of energy consumption, sustainable aspects, faster and durable construction, durability of construction materials etc., have lead to the development of new and innovative additive materials for the most widely used cement based construction materials i.e. cement mortar and cement concrete which are weaker in tension. From 1960s onwards extensive and exhaustive research work related to the improvement in tensile behaviour of concrete using inclusion such as short discrete steel fibres in concrete matrix have been carried out. So far several innovative developments relating fibres inclusions to cement concrete matrix have been carried out that includes fibre material, texture, shape, length, diameter etc. In this efforts, the development and availability of macro synthetic fibres (MSFs) of different characteristics in construction market is one of such recent additions. Macro synthetic polymeric fibres have the potential to enhance the post cracking properties of hardened cement based materials besides potential for improvement in their other properties including durability. The study aims at disseminating information about the potential uses of macro synthetic fibres in cement concrete for designers, clients and users who are little familiar with use of MSFs for overlay for pavements and bridge deck.

**Macro Synthetic Fibres (MSFs)**

MSFs are commercially available in the market since the late 1990’s. As per the EN 14889 – Part 2, a macro synthetic fibre is a short discrete fibre with diameter greater than 0.30 mm and length between 30 mm and 65 mm. According to ASTM D7508 (reapproved 2015) the general requirements for MSFs are that the individual fibre has a diameter greater than or equal to 0.3 mm and a tensile strength greater than 50,000 psi (350 MPa) with length between 1/2 in (13 mm) and 2.5 in (65 mm). Generally, the ‘equivalent’ diameter of MSFs ranges from 0.3 to 1 mm, with tensile strengths between 350 to 700 MPa. The modulus of elasticity of these fibres is typically around 3 to 10 GPa with aspect ratios ranging from 70-90. MSFs have dimensions similar to steel fibres but are manufactured from materials with a specific gravity in the order of 0.9. They maintain their mechanical properties in alkaline as well as in acidic environments. The shape of the fibres is cylindrical, ‘crimped’ or ‘ribbed’, thin and flat, with a special textured surface. Generally, the MSFs are either straight or deformed. A straight fibre is visually straight, although it may have various surface textures and embossing. Some of the most commonly available MSFs are shown in figure 1. The fiber’s aspect ratio and geometry are selected based on the basis of its tensile strength and its bonding strength with the concrete matrix to maximize pullout resistance so that the fiber does not break and provides the desired enhancement in the property or properties of concrete for which these have been added. The key to efficient fibre performance is the bond between the fibre and the hardened cement concrete matrix. Some fibres have surface irregularities to strengthen the bond with the cement paste, while others rely on the physical bond between the fibre surface and the hardened cement paste.

MSFs are used to reduce the widths of cracks resulting from repeated live load applications as well as environmental factors such as to control cracking in concrete deck slab and concrete pavement slab due to thermal movements or both, and also to provide post-cracking energy.
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absorption capacity that is the toughness. MSFs may also be used for improvement in structural capacity of concrete to some extent. However, with the current state of the design practice, it is not allowed to fully consider the increased structural capacity from macro-fiber reinforcement in the design process.

**Theory relating performance of MSFs in Cement based materials**

The performance of macro synthetic fibres (MSFs) in cement-based materials rely on their bond strength with the matrix. In most cases, the characteristics of the cement paste of the matrix is improved with the addition of materials like coal-based fly ash, or silica fume, or similar supplementary cementitious materials, besides water reducing agent (WRA) to improve the bonding with MSFs. For optimum fibre efficiency, the elastic modulus of a fibre should closely match the elastic modulus of the hardened cement paste in which the fibre is embedded. This allows the fibres to transfer stresses across a crack after cracking has begun. As the elastic modulus of MSFs is much less than hardened concrete (MOE for paving concrete is commonly around 26-30 GPa), hence they are generally designed to break, contrary to the failure mode of steel fiber reinforced concrete (SFRC), which is due to the fibres pull out of the cemented matrix. This should be kept in mind while considering the intended application of MSFs in concrete.

MSFs are generally prescribed for use in shotcrete for ground support applications and in concrete for slabs on grade where wider cracks (mostly wider than 0.4 or 0.5 mm) can be accommodated and for concrete slabs where the closer joint spacing is provided. MSFs are particularly beneficial when larger crack widths (say >0.5 mm), can be accommodated in the concrete as they need to elongate or ‘stretch’ before they are able to transfer significant amounts of stress across the cracks.

**Design of MSF Reinforced Concrete**

The material properties of MSF reinforced concretes such as residual tensile strength, energy absorption capacity, (i.e toughness) are determined by beam tests in accordance with ASTM C1609-06, ASTM C1550-19. The results obtained can be used to calculate the performance of the post-cracked concrete specimen and for the concrete element where the in-service performance relies on the post-cracking behaviour of the concrete.

MSFs are not designed to replace steel bars or mesh where either is used for structural reasons. Since the inclusion of such fibres may enhance concrete’s post cracking capacity, they can be used in some designs based on plastic analysis such as ground supported slabs and rock support when used in shotcrete. MSFs can be used to replace steel mesh for shrinkage control in ground supported concrete slabs. If MSFs are used as a replacement for shrinkage, then it is important that the fibre type and dose rate provide a similar level of direct tensile capacity. This will ensure that crack control is provided, but due consideration should be given to maximum acceptable serviceability limit state crack widths.

The dosage of MSFs should be sufficient (0.2 to 1.0% by volume) to give an equivalent flexural strength of at least 0.3; otherwise the concrete should be treated as plain. The ‘design using MSFs is still in its infancy and there are no universally accepted methods’ [CSTR 65]. The suitability of a particular fibre for a particular application will depend on appropriate design rules being followed. The study [CSTR 34, 2016] reports that certain types and dosages of MSFs can enhance the equivalent flexural strength ratio values, which should be determined by testing (as for steel fibres reinforced concrete).

**Properties of Macro Synthetic Fibres Reinforced Concrete**

Hardened concrete containing MSFs can generally be described as having post crack energy absorption capacity. At normal dosage of MSFs addition, the fibres should not have any adverse affect on the compressive strength and durability of the concrete, if the reduction in workability due to the fibres addition is compensated by the addition of a good water reducing agent (WRA). But, at higher fibre dosages, MSF may cause the plastic concrete to appear stiff and harsh; in such cases, a proper mix design and use of chemical admixtures in order to avoid any placement and/or compaction issues, are needed. In some situations, an increase in cement paste content and/or the addition of a small amount of air entraining agent, or some suitable water reducing agent (WRA), can create a workable concrete mix.
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According to CSTR 65, there is limited information on how the physical properties of MSFs change over time and, therefore, how the long-term structural performance of the concrete may be affected. The modulus of elasticity and creep of the fibres should be kept in mind.

**CE Approved Macro Synthetic Fibres Manufactured to EN 14889-2**

In Europe, MSFs can have a CE label for structural use, certifying compliance with EN 14889-2, Class II, i.e. fibres >0.3 mm in diameter. MSFs (for structural use) should not be used at a lower dosage than the declared minimum value stated on the CE label. In our country, we lack such information for structural use of MSFs.

**Mix Design/Proportioning**

Generally, the dosage rates of MSFs range from 2 to 7 kg/m³ of concrete, i.e. about 0.25 to 0.75% by volume, depending on the requirements for meeting the desired improvement levels, post cracking. The dosage rate needed to achieve the desired residual flexural strength varies depending on the fibre material and fibre dimensions. Increasing the dosage of fibres to achieve a certain toughness performance target is likely to have an adverse impact on the workability of the concrete. To overcome the loss in workability of the concrete, the addition of a water reducing admixture is recommended without compromising the strength, durability, and other properties of the concrete mix design. Another way to compensate the loss of workability due to the addition of MSF is by increasing the paste content of the concrete mix. For cold areas where the concrete slabs are exposed to freezing weather, a slight increase in the dosage of a suitable air entrainment admixture may be used to ensure the durability of concrete, primarily because of the increased surface area of the fibre in the concrete mix.

**Using MSFs in Concrete**

**Batching and Mixing of Concrete Containing MSF**

MSFs can be added to the concrete at a ready mix plant during batching and mixing, or it can be added to the ready mix transit concrete truck at arrival on site. In either case, checks should be made to ensure proper fibre dispersion throughout the concrete. If the fibres are mixed at site, the concrete mix should be mixed for at least five minutes at maximum mixing speed of the transit mixer to disperse the fibres throughout the load of concrete. A typical concrete mix containing MSFs is shown in Figure 2.

**Placing and Finishing of Concrete**

No special equipment is required for placing and finishing of the concrete mix containing MSFs. Concrete mix containing MSFs may be placed and compacted using the same methods as used in a plain concrete mix; however, an extra precaution should be taken during finishing to minimise the appearance of fibres on the surface of the slab. Appearance of an excessive number of fibres on the finished surface of the slab may indicate inadequate mix design, fibre type, dosage, and placing/finishing techniques. During broom finishing and tinning, some of the macro synthetic fibres are likely to be seen on the surface of the concrete pavement. Hence, inclined texturing is preferred. However, fibres protruding out will not harm as they will quickly wear off due to abrasion. In some cases, these fibres are cut to match the surface of the pavement.

**Sampling and Testing**

Sampling, testing and quality control procedures for concrete containing MSFs are not different from the conventional concrete. However, extra attention is to be paid during casting of MSF reinforced concrete beam specimens for flexural testing. Care must be taken to fill the beam moulds in the specified manner in order to minimise variances in test results due to changes in fibre alignment within the beam mould. Some manufacturers of MSFs offer test methods for determining the dosage in plastic concrete.

**Areas of Application**

The major applications for MSF reinforced concrete are in the following:

- Sprayed concrete that is shotcrete as ground support in underground works
- Construction of footpaths
- Concrete pavements such as thin and ultrathin white topping overlays on suitable distressed bituminous roads. Pavement concrete containing MSFs increases the ductility in comparison with plain concrete (extent of enhancement depends on the amount and type of MSFs) which is very much suitable for concrete overlay directly on milled surface for the construction of a thin and ultrathin white topping as a rehabilitation and strengthening of distressed bituminous surface. Typical milled surfaces of bituminous pavements

![Figure 2: Concrete mix containing MSFs](image)

![Figure 3: A typical milled surface of bituminous highway pavement](image)

![Figure 4: A typical bituminous surface milled for receiving a layer of thin white topping](image)
ready for receiving concrete for overlay on a highway and a city road are shown in figures 3 and 4, respectively, clarifying a need for concrete mix with MSFs on plain concrete for better performance and a longer service life.

- Precast concrete such as pipes, track paving slabs, etc.
- Concrete overlay on both newly constructed and rehabilitated bridge decks. In such applications, the improved toughness behaviour of concrete due to the addition of MSFs increases the service live of deck slabs because of a drastic reduction in the rate of crack propagation, improvement in behaviour under impact load, etc.

**Summary**

The availability of MSFs of different characteristics in the construction market as inclusion in cement concrete is a recent addition in the list of innovative techniques for incorporating/improving the engineering properties of cement-based materials such as concrete and mortar. Macro synthetic polymeric fibres have the potential to enhance the post cracking properties of hardened cement-based materials, besides improving other properties, including durability. Enhancement in crack arresting properties, post crack behaviour, including residual flexural strength, abrasion resistance, ductility, resistance to disintegration of cracked slab panels result in the construction of more durable concrete overlays such as thin, ultrathin, conventional and bridge deck overlays for rehabilitation and strengthening.

**Acknowledgements**

The permission of Director-CRRI Prof. Satish Chandra to publish this work is gratefully acknowledged and also the help provided by Adarsh Kumar and Garima during the preparation of the manuscript.

**References:**

The Himalayas situated along India’s northern border rise to considerable heights. While the lower reaches of these mountains experience intense rains, in the higher altitudes heavy snowfall is common. Areas experiencing snowfall can be grouped into two categories:

(i) Areas having altitudes between 2500 m to 3000 m where snowfall is not heavy and snow clearance operations are relatively easy.

(ii) High altitude areas above 3000 m where intensity and periodicity of snowfall is more, and avalanches, frost, blizzards and icing are also encountered.

Due to the high availability of water from rains and snow in the Himalayan region, many of India’s perennial rivers originate here. On the flip side, large amount of moisture in sub-soil leads to slope instability and road pavement distress. Pavement performance in the region is affected by freezing and thawing, thermal stresses induced by temperature variations, and use of studded tyres/track wheeled vehicles. Hence, high altitude areas which are subjected to heavy snowfall and frost action necessitate special consideration for design and construction of pavements.

Frost Action in Road Pavements

The distress caused to road pavements due to freezing and thawing of water which is trapped within subgrade or subsoil immediately below the subgrade is called frost action. Frost action refers to two separate but related processes: frost heave which results in upward movement of pavement layers and subgrade due to expansion of accumulated moisture as it freezes and thaw weakening resulting from soil saturation as ice melts. The Himalayan region, being vast, considerable variations occur in soil types, it’s mineralogy, origin and deposition, ground water conditions, climatic conditions, etc. Certain combinations of these conditions make subgrade unsuitable for road works. Frost action in subgrade soil is one such issue. Moisture in subgrade soil can lead to formation of frost during winter months depending upon altitude of the road. Frost heaving can result in cracks and poor riding quality in the pavement, while frost thawing leads to pavement failure due to loss of subgrade support.

Three conditions are required for frost occurrence:

(i) Soil which is susceptible to frost formation
(ii) Temperature in soil should be below freezing point of water
(iii) Moisture (water) in the soil

If these conditions occur uniformly, heaving will be uniform. However, under actual field conditions, variations in these three factors from place to place results in differential heaving. In some locations, more than one cycle of freezing and thawing may occur within a year, and this would be more damaging to road pavement than one single but longer cycle of freezing and thawing. Thawing generally happens from top...
downwards. Hence, during thawing period trapped water above frozen soil saturates pavement layers and drastically decreases bearing capacity of subgrade soil.

**Sources of Water for Frost Action**

Water which contributes towards frost action in pavements can come from two sources (a) Surface water which enters the pavement through cracks and joints (b) Subsurface water. Road pavements are not entirely impermeable and moisture infiltration can occur during rain or snow melting. Pavements which have thin bituminous surface course are especially vulnerable in this regard. Subsurface water can enter into subgrade soil from three sources, (i) Ground water (ii) Capillary Water and (iii) Lateral movement of moisture within sub-soil. A groundwater level within 1.5 m of the proposed subgrade top level usually results in availability of sufficient water for frost action. In case of clayey subgrades, this water table depth even in excess of 3 m can result in frost action since capillary rise of water is very high in clayey soils. Sometimes it is seen that, even though normal water table may be at considerable depth below, ‘perched water table’ if present, can contribute considerably towards frost action. When water is drawn upwards from ground water through capillary action, it results in moisture entry into soil layers much above water table. In hilly areas, lateral movement of moisture from a pervious strata is fairly common when road is located in a side hill cut which intersects such pervious strata.

**Soils Prone to Frost Action**

Frost action generally does not happen in clean, well drained sands, gravels, crushed rock, and other similar granular materials. They have high permeability, which allows trapped water to drain out quickly. Additionally, considerable amount of voids present in such soils permit water to freeze without segregation into ice lenses. On the other hand, silts are highly frost susceptible. Relatively smaller sized voids found in silty soils, high potential for capillary action, and better permeability than clayey soils, accentuate frost action problem in silty soils. Clays have a high potential for capillary rise of water. However very low permeability of clays results in lower capillary action. Consequently, frost may occur in clayey soils, but its impact will not be as severe as silty soils. Casagrande provided following rule for identification of frost susceptible soils:

- In case of non-uniform soils (soils having coefficient of uniformity ‘$C_u$’ value greater than 5), any soil having more than 3 per cent of particles finer than 0.02 mm will be frost susceptible
- In case of uniform soils (soils having coefficient of uniformity ‘$C_u$’ value lesser than 5), any soil having more than 10 per cent of particles finer than 0.02 mm will be frost susceptible

The concept given by Casagrande was further modified by US Corps of Engineers and they proposed four groups (F1 to F4) of soils to identify frost susceptibility of different soils. This classification is given in IRC SP-48 Hill Roads Manual also (Table 1).

**Mitigating Frost Action**

Alleviation of frost action and its harmful effects on road pavement involves structural design considerations as well as other techniques. These methods can be categorised as given below:

- Removing and replacing frost susceptible subgrade
- Design the pavement structure based on reduced subgrade support
- Providing a capillary break/ encapsulation of frost susceptible layer

**Designing Road Pavement in Frost Prone Areas**

This case study road is in Himalayan region at an average elevation of 4250 m. This road gets covered by snow during winter. Snow collection and melting on the hill slopes and road section keeps repeating, especially during beginning and end of winter season. As a result, water seeps into subgrade soil as well as hill slopes, saturating it (Photos 1 to 3). Hence, frost formation in subgrade is expected. Before undertaking pavement design, subgrade soil collected from site was subjected to various tests and cement stabilisation.

<table>
<thead>
<tr>
<th>Group</th>
<th>Description</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>F1</td>
<td>Gravelly soils containing between 3 and 20 per cent finer than 0.02 mm by weight</td>
<td>Least frost susceptible and least thaw weakening</td>
</tr>
<tr>
<td>F2</td>
<td>Sands containing between 3 and 15 per cent particles finer than 0.02 mm by weight</td>
<td>Increased frost susceptibility and thaw weakening</td>
</tr>
</tbody>
</table>
| F3    | a. Gravelly soils containing more than 20 per cent finer than 0.02 mm by weight  
     b. Sands, except fine silty sands containing more than 15 per cent finer than 0.02 mm by weight  
     c. Clays with Plasticity Index (PI) value more than 12 | Frost susceptible and high thaw weakening |
| F4    | a. All silts including silty clays  
     b. Fine silty sands containing more than 15 per cent finer than 0.02 mm by weight  
     c. Lean clays with PI less than 12 | Higher frost susceptibility and high thaw weakening |
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The in-situ soil meets the gradation and plasticity requirements for cement stabilised materials as per MORTH Section 403 (Table 3). In-situ soil was stabilised using 43 grade Ordinary Portland cement (OPC). Strength development after stabilisation was excellent. IRC SP:72 which is used for design of road pavements for traffic up to 2 msa, specifies 1.7 MPa compressive strength at 7 days for sub-base course and 3.0 MPa compressive strength at 7 days for base course, when cement stabilisation is adopted. IRC SP:89, which is adopted for highway works, specifies compressive strength at 7 days to be from 1.5 MPa to 12 MPa for sub-base / base. Unconfined compressive strength test results of cement stabilised in-situ soil after 7 days of humid curing are given in Table 4. It can be seen that due to well graded nature of in-situ soil, cement stabilisation results in very high strength development.
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Pavement Design for Proposed Road - Alternative 1

Subgrade soil belongs to F2 category (Table 1), so, there is no need to replace the subgrade soil. Providing adequate thickness of road pavement can alleviate the frost action. The in-situ soil which will be used for subgrade is having very good CBR value (more than 20 per cent). Design traffic is expected to quite low, since it is located in a remote area. Design traffic was assumed to be 5 msa. IRC SP:48 proposes that design of pavement should be related to actual depth of frost penetration. Since daily temperature variations data was not available for the site, empirical design proposed in IRC SP:48, can be adopted. IRC 37 states that in frost prone areas, minimum thickness should be 450 mm even when subgrade CBR warrants a lesser thickness. IRC SP:48, states that structurally strong layer like dense bituminous macadam (DBM) and bituminous concrete (BC) would be needed since heavy machinery for snow clearance operations are to be used. Further to prevent percolation of water in the pavement layer, pavement cross section suggested in Table 5 should be adopted for full formation width, leaving no gap between edge of the pavement and drain or parapet.

Pavement Design for Proposed Road - Alternative 2

The in-situ soil is well graded gravelly sand. After stabilising with cement, in-situ soil develops very good strength. Hence, cement stabilised pavement section as per IRC 37 is proposed as an alternative (Table 5). As suggested in Alternative 1, to prevent percolation of water in the pavement layer, the pavement cross section suggested in Table 5 should be adopted for full formation width, leaving no gap between edge of the pavement and drain or parapet.

Additional Issues Pertaining to Black Top Layers

- Warm mix additive is recommended to be used in DBM and BC mixes to ensure adequate compaction even at lower temperature, during the compaction process of bituminous mixes. IRC SP:101 ‘Interim Guidelines for Warm Mix Asphalt’, provides details of warm mix modification.
- Polymer modified bitumen (PMB) is recommended as binder for the wearing course. Due to very low temperature conditions expected at site, only elastomeric modifiers (viz. SBS) are preferred and recommended. Mixing and laying temperatures shall be strictly adhered to as per specifications (IRC SP:53).
- In binder course as well as wearing course, use of anti stripping agent is recommended to prevent damage of bituminous layers due to the moisture ingress.
- Construction activities such as bituminous work and cement stabilisation should be completed before onset of winter season.

Acknowledgements

The authors are thankful to Mr M.N.Nagabhushana, former Senior Principal Scientist, CSIR-CRRI for his valuable contributions and association during the study.

References

- IRC SP:53, ‘Guidelines on Use of Modified Bitumen in Road Construction’, Published by Indian Roads Congress, New Delhi (2010)
- MoRTH Specifications for Road and Bridge Works, Published by Indian Roads Congress, New Delhi (2013)
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Flexible pavements are the most common type of pavement systems in the country. In addition to being convenient to construct, they are also cost-effective and easy to maintain. These pavements constitute the surface course and binder course and are made up of bitumen and mineral aggregates. Bitumen is the main binder which binds the aggregates together to act as a structural layer. It is very important to control the properties of bitumen as the performance of the constructed pavement is based on the properties of the bitumen used and subjected to different loading and climatic conditions.

To ensure that the bitumen used for the road construction is of the required quality, it should meet the specified requirements for an appropriate grade. The need for a grading system for bitumen was necessitated by the fact that about 250 uses of bitumen have been reported (Read and Whiteoak 2003). In pavements also, it is used for many different applications. Each application has specific requirements which it should meet. The grading system adopted for bitumen simplifies the entire process by specifying different grades to be used for different applications. The grading system has also evolved considerably over the years based on field performance and appropriate method of testing (Kandhal 2007).

**Why bitumen modification is required?**

A direct reflection of the growth of a country’s economy can be seen in the increased pace of development in its infrastructure sector where roads constitute a major component, and in which a major portion of the infrastructure funds is spent. In the present era of economic development, the traffic demands placed on our pavements are significantly more than in the past. The increase in traffic growth coupled with increased axle loads and climatic variations has posed challenges for the road agencies to look into the demands made on the bitumen pavement construction. A quest for improved road performance led to the modification of bitumen. In this regard, as early as in 1980’s, modification to base bitumen was done by addition of certain additives like polymers, natural rubber, crumb rubber etc. to enhance the mechanical behavior of bitumen by physical modification. Later, chemical modification was also attempted using polyethylene, poly phosphoric acid etc (Kumar and Veeraragavan 2008). Table 1 indicates the categories of modified bitumen as specified in IS:15462 (2004).

Each of these categories is further subdivided into three grades: based on penetration value for Type A, B and C, and based on softening point value for Type D. So, Type A modified bitumen is further graded into PMB (P)120, PMB(P)70 and PMB(P)40. Type B modified bitumen is graded into PMB (E)120, PMB(E)70 and PMB(E)40. Type C modified bitumen is graded into NRMB120, NRMB70 and NRMB40. Similarly, Type D modified bitumen is graded into CRMB50, CRMB55 and CRMB60. The viscosity was also incorporated in the specifications with ranges given against each bitumen grade. The use of modified bitumen in road construction significantly reduces the amount and severity of pavement distresses and increase service life. The primary benefit of using modified binders is improved rutting resistance, improved...
Flexible Pavement

thermal cracking resistance, along with secondary benefits such as an improvement in the overall mixture durability. Additionally, some modified binders provide improved stripping (moisture damage) resistance. An additional four to six years of pavement life from a pavement constructed using modified bitumen is a reasonable expectation (IRC:SP:53 2010).

Performance based grading in IS:15462-2019

It is commonly known that bitumen plays the key role in the behavior of bituminous mix and the overall performance of bituminous pavements. The accumulated strain in the bitumen, as a consequence of repeated traffic loadings, is responsible for the permanent deformation or rutting in the bituminous pavements. In order to identify the contribution of bitumen to pavement rutting, the parameter $G^\prime \sin \delta$ has been used (IS:15462-2004). The parameter $G^\prime \sin \delta$ is the high temperature specification parameter used to indicate the rutting performance and is obtained through DSR testing. In the DSR, a torque is applied to the bitumen sample placed between two parallel plates and response is measured. The specified criteria for rutting parameter $G^\prime \sin \delta$ is 1.00 kPa for unaged and 2.2 kPa for the RTFO-aged binder. The criteria remain the same regardless of the location of the pavement and the high temperature to which it might be exposed to. The minimum values of test temperatures at which these criteria must be met are also specified regardless of the location of the pavement.

However, researchers have reported that this rutting parameter ($G^\prime \sin \delta$) has poor correlation with field rutting (Carswell and Green 2000) and is inadequate in describing the rutting performance of polymer modified binders, in particular. In addition to the adoption of inadequate rutting parameter, the other shortcomings of IS:15462-2004 include:

- Viscosity test is specified to be conducted at one standard temperature (150°C) without regard to the climate in which the bitumen will be used.
- Only short-term aging is considered. The specification doesn’t take into consideration the long-term aging during the service life of the pavement.
- It also doesn’t adequately capture the low temperature behavior/performance of bitumen. Only Fraass breaking point is to be identified for a particular grade of bitumen. Fraass breaking point may be modified / changed due to the addition of modifier. Also, it has been reported that the Fraass breaking point generally has a poor correlation with the low temperature behavior of bituminous mixtures (Lu et al. 2017). So, the specifications do not adequately describe the low temperature behavior of bitumen.
- The specification requirements were different for the different types of additives, i.e. they were not blind to the modification.

From the pavement engineer’s point of view, modified bitumen is used to enhance the performance of the pavements, irrespective of the additive / modifier used for the modification purpose. Also, the properties of modifier are affected by the temperature and stress loadings. So, there was a need for a unified performance-based specifications for modified binders which should be blind to the modification. This essentially means that the specifications specify in clear terms the requirements for the particular binder grade; irrespective of the additive / modifier used to attain such properties. In other words, all bitumen of the same performance grade would be expected to perform the same in the same traffic / environmental conditions regardless of how they were produced. Such a specification would be a ‘win-win’ situation for both the bitumen users and producer. The producer is free to choose any particular additive / modifier for the modification purpose, based on his business interests, and meet the specified requirements. The user is confident of getting the modified bitumen (he need not worry about the additive/modifier used for the modification) which meets the performance-based requirements given in the specifications.

To take into account the above shortcomings, the performance-based grading was introduced in the revised specifications IS:15462 (2019). This was a tactical shift towards developing more robust specifications which relate well with the bitumen performance. Table 2 indicates the grades of modified bitumen specified in IS:15462 (2019) specifications.

The general format adopted for the nomenclature is PMB XX-YY. Here, ‘XX’ specifies the average maximum pavement temperature, at a depth of 20 mm, based on the high air temperature and latitude of the place of the project location. The data regarding the air temperatures can be obtained from the Indian Metrological Department (IMD). The formula relating air temperature and latitude with the pavement temperature is given below (IS:15462 2019):

$$ T_{20mm} = 0.9545 \times (T_{air} - 0.00618 L^2 + 0.2289 L + 42.2) - 17.78 $$

**(1)**

Where, $T_{20mm}$ = average maximum pavement temperature at 20 mm below the road surface; $T_{air}$ = high air temperature; and $L$ = latitude in degrees for the place of project location.

---

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Category of modified bitumen</th>
<th>Type of modifier used for modification</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a)</td>
<td>Type A – PMBi(P)</td>
<td>Pistomeric thermoplastics (eg - Polyethylene, Ethylene-Vinyl Acetate copolymer, Ethylene-Methyl Acrylate copolymer, Ethylene-Butyl Acrylate copolymer)</td>
</tr>
<tr>
<td>(b)</td>
<td>Type B – PMBi(E)</td>
<td>Elastomeric thermoplastic (eg - Ethylene Ter polymer, Styrene-Butadiene-Styrene block copolymer, Styrene-Isoprene-Styrene copolymer)</td>
</tr>
<tr>
<td>(c)</td>
<td>Type C – NRMB</td>
<td>Natural rubber and SBR latex</td>
</tr>
<tr>
<td>(d)</td>
<td>Type D – CRMB</td>
<td>Crumb rubber / treated crumb rubber</td>
</tr>
</tbody>
</table>
For Delhi, the lowest air temperature taken as minimum pavement temperature. The lowest air temperature is 'YY' specifies the minimum pavement used for Delhi conditions. Similarly, vessel (PAV).

<table>
<thead>
<tr>
<th>S. No.</th>
<th>Binder grade</th>
<th>Specified temperature ranges</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>PMB 54 – 10</td>
<td>Average maximum pavement temperature &lt; 64°C and Minimum pavement temperature &gt; (-10) °C</td>
</tr>
<tr>
<td>2.</td>
<td>PMB 70 – 10</td>
<td>Average maximum pavement temperature &lt; 70°C and Minimum pavement temperature &gt; (-10) °C</td>
</tr>
<tr>
<td>3.</td>
<td>PMB 76 – 10</td>
<td>Average maximum pavement temperature &lt; 76°C and Minimum pavement temperature &gt; (-10) °C</td>
</tr>
<tr>
<td>4.</td>
<td>PMB 82 – 10</td>
<td>Average maximum pavement temperature &lt; 82°C and Minimum pavement temperature &gt; (-10) °C</td>
</tr>
<tr>
<td>5.</td>
<td>PMB 76 – 22</td>
<td>Average maximum pavement temperature &lt; 76°C and Minimum pavement temperature &gt; (-22) °C</td>
</tr>
</tbody>
</table>

The estimation of average maximum and minimum pavement temperature can be done as explained in the subsequent example for Delhi city. For example, Delhi has high air temperature of 48°C and its latitude is 28.7°N. So, the average maximum pavement temperature computed is 69.7°C. Therefore, PMB 70 should be used for Delhi conditions. Similarly, ‘YY’ specifies the minimum pavement temperature. The lowest air temperature is taken as minimum pavement temperature. For Delhi, the lowest air temperature recorded is 3 °C, which is taken to be the minimum pavement temperature. So, the grade of PMB to be chosen for Delhi is PMB 70-10. This chosen grade is only based on environmental conditions; ‘grade bumping’ might be needed depending on the traffic plying on the specific pavement. The concept of ‘grade bumping’ has been discussed in subsequent section.

Apart from introducing the grading based on the average maximum and minimum pavement temperatures, the other two significant changes in the new specifications are the inclusion of non-recoverable creep compliance (Jnr) based on multiple stress creep recovery (MSCR) testing and the use of long term aging parameter ($G'/(sin \delta)$) with pressure aging vessel (PAV).

**Why was MSCR test included?**

During the measurement of the high temperature parameter, $G'/(sin \delta)$, an oscillating load to the bitumen is applied at relatively low strain. Under a very low stress and strain level, it is unlikely that the polymer network in the modified bitumen would be really activated. So, in the present testing framework, the polymer is only viewed as a filler material that stiffens the bitumen (FHWA 2011). This is one of the reasons why the existing rutting parameter does not accurately represent the ability of polymer modified binders to resist rutting. However, the polymer chains in the modified bitumen can be rearranged substantially with increasing stress levels. Such higher levels of stress and strain are applied to the bitumen in MSCR testing, thereby better representing the actual field conditions experienced by the pavement. By using the higher levels of stress and strain in the MSCR test, the response of the bitumen captures not only the stiffening effects of the polymer, but also the elastic effects.

The MSCR test (ASTM D7405 (2015)) is carried out using a dynamic shear rheometer (DSR). It is based on the well-established creep and recovery test concept for the purpose of evaluating the binder’s potential for permanent deformation. The procedure involves applying a consecutive series of static loads, followed by a period of recovery to a binder sample. Using the DSR, a one-second creep load is applied to the aged bitumen sample. After the one-second load is removed, the sample is allowed to recover for nine seconds. The test starts with the application of a low stress (0.1 kPa) for 10 creep/recovery cycles, and then the stress is increased to 3.2 kPa and repeated for an additional 10 cycles. The testing for MSCR is done at the selected actual high pavement temperature with no grade bumping. Two separate parameters can be determined in the MSCR testing: non-recoverable creep compliance ($J_{nr}$) and percentage of recovery (MSCR Recovery) during each loading cycle. Values are reported as the average of ten loading cycles at each shear stress level.

Physically, $J_{nr}$ is a measure of the amount of residual strain left in the binder specimen after repeated creep and recovery, relative to the applied stress magnitude in kPa. The MSCR percent recovery is a measure of how much the sample returns to its previous shape after being repeatedly stretched and relaxed. The parameter $J_{nr}$ has been found to correlate well with the field rutting data (D’Angelo 2009). If the bitumen meets the appropriate $J_{nr}$ specification, then it is expected that the binder will minimize its contribution to rutting.

Though the main requirement for $J_{nr}$ is determined at 3.2 kPa shear stress, the data determined at 0.1 kPa shear stress is also important. To minimize concerns that some bitumen may be overly sensitive to changes in shear stress and exhibit yielding at the higher stress level, another parameter $J_{nr,0.1kPa}$ has been specified, whose maximum value should not exceed 75%.

The formula to compute $J_{nr,0.1kPa}$ is given in Equation (2).

$$J_{nr,0.1kPa} = \frac{J_{nr,3.2kPa}}{J_{nr,0.1kPa}} \times 100$$

Where, $J_{nr,0.1kPa} =$ value of $J_{nr}$ at stress level of 0.1 kPa; and $J_{nr,3.2kPa} =$ value of $J_{nr}$ at stress level of 3.2 kPa.

**Grade bumping through non-recoverable creep compliance ($J_{nr}$)**

There was no concept of grade bumping in the original IS:15462-2004, however, the same has now been incorporated in the revised IS:15462-2019. The grade bumping is done on the basis of $J_{nr}$ value. With MSCR, the bitumen testing is done at the high environmental temperature that the pavement is expected to experience. This means, if the pavement climate grade is PG64, the testing would be done at 64°C. A lower value of $J_{nr}$ indicates a significant improvement in the stiffness of the bitumen. So, in order to accommodate for the higher traffic, lower value of $J_{nr}$ would be required.
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to reflect the increased stress the pavement will actually experience, without changing the testing temperature. Table 3 indicates the requirements of grade bumping for various service conditions.

### Conclusions and Way Forward

The present paper reviews the newly implemented IS:1546-2019. The new specifications include the MSCR testing and the grade bumping is done on the basis of Jnr value. Based on the review, the following conclusions may be drawn:

- The non-recoverable creep compliance (Jnr) is better correlated with rutting potential than the original rutting parameter (\(G'/sin \delta\)).

- The MSCR testing is done corresponding to the actual pavement high temperature, regardless of traffic speed and loading. To account for the traffic loading and/or speed, grade bumping is done on the basis of the value of Jnr parameter, as given in Table 3.

- There is a criterion to eliminate the binders that are overly stress sensitive and potentially susceptible to rutting in the field. This criterion is given by Jnr and its acceptable value is less than or equal to 75 %.

- The revised specifications for modified bitumen IS:15462 (2019) has still retained the conventional elastic recovery (ER) test (in theductilometer) to evaluate the presence of polymer in binders. This may be replaced with the MSCR recovery which provides a better estimate of the established polymer network in the binder. Higher value of MSCR recovery indicates more robust cross-linked polymer structure.

- There is a criterion to eliminate the binders that are overly stress sensitive and potentially susceptible to rutting in the field. This criterion is given by Jnr and its acceptable value is less than or equal to 75 %.

- Better test methods such as bending beam rheometer testing should be included in place of Fraass breaking point to describe the low temperature behavior of modified bitumen.

### Acknowledgement

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### Disclosure statement

No potential conflict of interest was reported by the authors.

### References


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**Table 3: Jnr requirements for grade bumping**

<table>
<thead>
<tr>
<th>Service Condition</th>
<th>Jnr values</th>
<th>Traffic Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard (S)</td>
<td>2.0 kPa⁻¹ ≤ Jnr &lt; 4.5 kPa⁻¹</td>
<td>Traffic repetitions less than 10 million Equivalent Single Axle Loads (ESALs) and more than the standard traffic speed (more than 70 km/h)</td>
</tr>
<tr>
<td>Heavy (H)</td>
<td>1.0 kPa⁻¹ ≤ Jnr &lt; 2.0 kPa⁻¹</td>
<td>Traffic repetitions between 10-30 million ESALs or slow-moving traffic (20 to 70 km/h)</td>
</tr>
<tr>
<td>Very Heavy (V)</td>
<td>0.5 kPa⁻¹ ≤ Jnr &lt; 1.0 kPa⁻¹</td>
<td>Traffic repetitions of more than 30 million ESALs or very slow moving/standing traffic (less than 20 km/h)</td>
</tr>
<tr>
<td>Extremely heavy (E)</td>
<td>Jnr &lt; 0.5 kPa⁻¹</td>
<td>Traffic repetitions of more than 30 million ESALs and very slow moving/standing traffic (less than 20 km/h)</td>
</tr>
</tbody>
</table>
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Roller Compacted Concrete (RCC) has been developed as a new construction material during the 1960s for dam applications. ACI 325.10R defines Roller Compacted Concrete as concrete compacted by vibratory roller. By definition it is simply a concrete mix that has a stiff consistency (Zero Slump) which enables it to spread with a special type of paver and which can be compacted under the wheels of vibratory roller. RCC can be placed without formwork at large production rates and can be considered as more economical than conventional pavement quality concrete which is used in rigid pavement applications.

Material properties of RCC have a wider range of variation than the pavement quality concrete. Ordinary Portland cement of different grades, PPC and PSC, different mineral admixtures like Pulverised fuel Ash, Ground Granulated Blast Furnace Slag etc., and aggregates not satisfying the grading requirement usually for normal or conventional concrete can be used for its preparation. RCC can be used for pavement applications and this new paving method was proposed to be the best cost-effective and durable solution for rigid pavements and similar applications.

Roller Compacted Concrete Pavement (RCCP) material was successfully used in Canada in heavy industrial areas under severe frost conditions. The material had been doing well for carrying heavy traffic wheel loads with low construction cost. After that experience, several advances have been introduced to RCC. Most of these advances are focussed towards improving quality of the surface and durability. Also, an improvement in rideability came when special pavers were employed for placing the RCCP. With the advent of this procedure, RCC now unites the quality of concrete material and the low cost of bitumen and construction procedure of the bituminous pavements.

The low water-cement ratio varying between 0.30 to 0.40 assists in providing very high strengths. RCCP material is placed without formwork, with no surface texturing and no finishing. Hence it can be constructed very rapidly requiring less labour than traditional pavement quality concrete (PQC). With low water content used in the RCC mixture and low water-binder ratio, RCC usually has strengths greater than conventional concrete. To satisfy the economy of construction of RCC over PQC, smoothness and surface quality of RCCP suffer.
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Applications
Considering the limitations of the Roller Compacted Concrete, its major application is for industrial pavements such as:

- Industrial access roads
- Parking areas
- Shipping yards and port terminals
- Truck terminals
- Bulk commodity storage yards
- Aircraft Apron
- Urban streets, rural roads and parking paths
- Heavy commercial parking lots (Surface Car Parking)

Advantages
Roller Compacted Concrete Pavement (RCCP) has the following advantages when compared to the conventional pavements.

- It has high flexural and compressive strength.
- Reduction in construction time.
- Little Maintenance costs
- High freeze-thaw durability
- Reduced cracking and shrinking
- Resists abrasion even under heavy traffic loads and volume
- It has more resistance for high temperature
- More Durability and high resistance to chemical attack

Limitations of Roller Compacted Concrete

- The surface of RCC is rougher than other pavements and not suitable for high speed traffic.
- The construction of adjacent slabs and also multiple horizontal lifts in same layer shall be placed within an hour to make sure the good bonding between layers.
- It is very difficult to compact the pavement layer towards the edges and hence most specifications are forced to limit the percent compaction to 96% modified proctor density.
- Generally, the use of admixture on RCC may be higher than conventional concrete pavements because of the dryness and stiffness of the mixture.

- In hot weather concreting of RCC for paving requires additional attention to decrease the possibility of water loss due to evaporation.

Considering the versatility of RCC over conventional pavements and its ease of application and its durability as compared to traditional bituminous pavements it becomes clear that the roller compacted concrete is a suitable paving material. Also, when considering the ever-increasing cost of petroleum-based products such as bitumen it becomes quite evident that RCC is likely to be the paving construction material of the future.

Roller Compacted Concrete Pavement Construction Procedure

Connectivity of rural roads is an important criterion in rural development. Low volume rural roads in India, including other district roads (ODR) and village roads (VR), occupies about 80% of the total roads of the country. At present these roads are provided with asphalt pavements. Most of these roads are potholed and distressed due to variety of reasons. Therefore, there is an urgent need to construct and maintain the rural roads in an optimal manner.

Alternative Solutions
A place where soil is soft and of poor strength, aggregate is costly and poor drainage conditions are prevailing; rigid pavement is best alternative to flexible pavement. Rigid pavement of following types is suggested in place of flexible pavements:

- Plain Cement Concrete Pavement (PCP) with M-30, M-35 & M-40 Grade concrete
Rigid pavements consist of a number of joints, which reduces stresses caused due to temperature changes and this is a principal cause for inconvenience to the road users. IRC: 101-1988 specifies technique of continuously reinforced concrete pavement which reduces the need of expansion and contraction joints; and thus improves riding quality and reduces the maintenance cost compared to plain cement concrete pavement (PCP). For the construction of conventional Continuously Reinforced Concrete Pavement (CRCP), percentage of steel required is 0.7-1.0%. Provision of steel reinforcement is important to arrest the cracks that occur in the concrete. Compared to flexible asphalt pavements construction, the process of construction of reinforced concrete pavements is difficult and costlier and involves more manpower.

RCC can overcome the problems usually encountered with flexible asphalt pavements or conventional plain or reinforced cement concrete pavements. RCC is the commercial name used for concrete placed with conventional hot mix asphalt paving equipment, then compacted with vibratory rollers. The strength properties of RCC are similar to that of a conventional concrete and consists of the same basic ingredients as conventional concrete; but RCC is dry mix made with lower water cement ratio and consists of mixture of dense graded aggregates, cement and water. The major difference between RCC mixtures and conventional concrete mixtures is that RCC has a higher percentage of fine aggregates, which allows for tight packing and consolidation.

The material is carried in dump trucks, placed into an asphalt-type paver equipped with a standard or high-density screed and then compacted under steel wheel rollers. Steel Drum Finish Roller with smooth rubber rear wheels and a vulcanized rubber drum is used to produce final surface texture. The time required for placing and compaction process is critical to obtain adequate density, strength, and smoothness of the finished RCC pavement. The concrete is placed and compacted fresh and at workable stage i.e., usually within 60 min of delivery. Due to stiff consistency it remains stable under vibratory rollers, yet wet enough to permit adequate mixing and distribution of paste without segregation.

Structural behavior of RCC is similar to that of conventional paving concrete, and so the design procedure follows the methodology used for concrete pavements.
Ports are among key components of country’s infrastructure whose performance metrics have improved considerably over years. While Indian coastline has 12 major ports handling about 75 percent of India’s port traffic, other (intermediate and minor) ports, about 200 in number, are serving the remaining marine traffic. Recent Policy initiatives of Govt. of India regarding ports have yielded results and there has been an upsurge in terms of total cargo handled at major ports. However, infrastructural facilities of ports within are yet to match the demands due to increase in cargo magnitudes and the existing facilities are falling short and are overstressed. Consequently, the port roads, among others, are deteriorating fast under heavy loads coupled with environmental and climatic factors and need a well conceived developmental approach; both in new constructions as well as in Maintenance and Rehabilitation/upgrading (M&R) phase.

Any comprehensive Port Development Guidelines (PDG) is supposed to assist proponents with the development and construction of new infrastructure including roads and/or the modification of existing infrastructure, within ports held under the jurisdiction of the port trust/authority. The performance requirements stipulated for port land transportation facilities, including roads, within the scope of PDG, shall ensure that the proposed facilities comply with requirements of the land, geotechnical, meteorological, state of sea, environment, tourism and traffic conditions of the port and its hinterland. Port transportation facilities should also have structural stability against self weight, earth & water pressure, waves, water currents, wind, imposed loads, heat, collision of huge vessels, earthquake and ground motions.

Road pavements are the integral and vital part of the land transportation structures and need to be paid the due attention for deriving the optimal benefits under the objectives of port development phase. For this reason, the selection of type, the geometrical and compositional characteristics, the design, construction, quality assurance and maintenance during operation attain significance. The techno-economic considerations constitute a major decisive approach for the development or upgradation of a port road network. Port roads are threatened by tidal conditions, do need a special contemplation as the soil strata remains marshy and weak, or perhaps the weakest. Therefore, a careful consideration involving the pavement structure is to be made, both during new addition of road lengths or M&R of existing roads.

Port Road Pavements

Generally, two basic types of road pavements are constructed in India; either flexible, the most widely used or the rigid pavement, as the next choice and obviously port roads are also constructed with either of these. Though there are further sub groups of pavements; surfaced and unsurfaced in flexible and plain or reinforced in rigid, in simple terms, a flexible pavement can be defined as a pavement layer comprising of a bed of compacted soil, granular layers and a layer or two of bituminous surfacing. Rigid pavements, on the other hand, are made from a well compacted granular layer / low strength concrete layer (DLC) or both laidover soil and covered by plain or reinforced concrete slabs. Subsequent to these common types, India has been gradually introducing composite pavements/use of treated layers below the bituminous top, short panelled concrete and block pavements.
The structural capacity of flexible pavements is attained by the combined action of the different layers of the pavement and hence depend on their ability, in turn. Flexible pavements are designed in such a way that the stress reaching the subgrade is negligible so as to not to exceed the bearing capacity of the subgrade soil. Consequently, the type, thicknesses and quality of the layers above the subgrade vary depending upon strength of soil affecting the cost of the pavement structure. For this reason, port roads may demand higher layer thicknesses and/or basal reinforcement techniques.

Rigid pavements are named so because of the high flexural rigidity of the concrete slab and hence the pavement structure deflects very little under loading due to the high modulus of elasticity of their surface course. The concrete slab is capable of distributing the traffic load into a large area with small depth which minimises the need for a number of layers to help reduce the stress.

During the design of port road pavements with given poor soil and expected heavier traffic load of vehicles and cranes, very often the question of choosing between these two types of pavements; flexible and rigid, comes to the fore. Many factors influence selection of the type of pavement to be constructed. Some of the main factors include; soil characteristics, traffic, material properties, climate, environment including depth of water table, construction considerations, and cost comparison. There are also secondary factors such as; performance of similar pavements in the area, continuity of the cross section, conservation of materials and energy, availability and use of local materials, traffic safety, traffic noise mitigation, experimental features, and agency preferences.

Hence, during the design and construction stages of port road pavement, it is very important to analyse the present situation with all the factors that have an impact on future structure. For such considerations, the basic characteristics of both variants of pavement are listed in the following table 1. While the above philosophy and discussions revolve around the basic pavement types involving flexible and rigid pavements, the container and stock yards are being provided with Interlocking Concrete Pavements (ICP) also and available guidelines indicate about the techniques and methods for design and construction.

### Design Considerations and Design Strategy

The design of pavement significantly depends of soil conditions and the amount of traffic loads expected to be carried during its design life. Flexible pavements in India are designed based on California Bearing Ratio (CBR) of subgrade soil and expected number of cumulated axles (measured in million standard axles) during the design life of the pavement or axle load spectrum to arrive at Cumulative Damage Factor (CDF) for rigid pavements. The pavements are normally designed for a period of 15-20 years in case of flexible and 30-40 years in case of rigid pavements. The Indian Roads Congress (IRC) method of design allows use of conventional as well as stabilised and recycling of materials appropriately in

### Table 1: Comparative Analysis of the Basic Characteristics of Flexible and Rigid Pavements

<table>
<thead>
<tr>
<th>Sl No.</th>
<th>Flexible Pavements</th>
<th>Rigid Pavements</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Deformation in the sub grade is transferred to the upper layers</td>
<td>Deformation in the sub grade is not transferred to upper layers</td>
</tr>
<tr>
<td>2</td>
<td>Design is based on load distributing characteristics of the component layers</td>
<td>Design is based on flexural strength or slab action</td>
</tr>
<tr>
<td>3</td>
<td>Carries low flexural strength</td>
<td>Carries high flexural strength</td>
</tr>
<tr>
<td>4</td>
<td>Load is transferred by grain to grain contact</td>
<td>Load transfer by grain to grain do not exists</td>
</tr>
<tr>
<td>5</td>
<td>Have low completion cost but repairing cost is high</td>
<td>Have low repairing cost but completion cost is high</td>
</tr>
<tr>
<td>6</td>
<td>Have low life span (High Maintenance Cost)</td>
<td>Life span is high (Low Maintenance Cost)</td>
</tr>
<tr>
<td>7</td>
<td>Surfacing cannot be laid directly on the sub grade but a sub base is needed</td>
<td>Surfacing can be directly laid on the sub grade</td>
</tr>
<tr>
<td>8</td>
<td>No thermal stresses are induced as the pavement have the ability to contract and expand freely</td>
<td>Thermal stresses are more vulnerable to be induced as the ability to contract and expand is very less in concrete</td>
</tr>
<tr>
<td>9</td>
<td>Any expansion joints are not needed</td>
<td>Expansion joints are needed</td>
</tr>
<tr>
<td>10</td>
<td>Strength of the road is highly dependent on the strength of the sub grade</td>
<td>Strength of the road is dependent to lesser extent on the strength of the sub grade</td>
</tr>
<tr>
<td>11</td>
<td>Compactive rolling of the surfacing is needed</td>
<td>Compactive rolling of the surfacing in not reeced</td>
</tr>
<tr>
<td>12</td>
<td>Road can be used for traffic within 24 hours</td>
<td>Road cannot be used until 14 days of curing</td>
</tr>
<tr>
<td>13</td>
<td>Force of friction is less</td>
<td>Force of friction is high</td>
</tr>
<tr>
<td>14</td>
<td>Damaged by Oils and Certain Chemicals</td>
<td>No Damage by Oils and Greases</td>
</tr>
</tbody>
</table>
flexible pavement layers and thickness of each layer is then computed using the layer theory based algorithm or read from the templates given in the guidelines.

Rigid pavements thicknesses are computed for overcoming the expected damage till the design life, normally for a period of 30-40 years and thickness design of rigid pavements are influenced by traffic loading, subgrade soil, moisture, and temperature differential. First, the thickness of rigid pavements is designed for fatigue failure. The computed thicknesses of the pavements are then checked for the critical combination of load stresses and temperature stresses.

Indian Port Authority Recommendations for Pavements

Most of the Indian Port Development Guidelines (PDG) suggests that pavements are designed, constructed and maintained according to the standards and specifications available and applicable for the major land road networks. This implies that the design and specifications comply with Indian Roads Congress (IRC) and Ministry of Road Transport and Highways (MoRT&H) guidelines which are in vogue. Since IRC Guidelines are available for both flexible and rigid pavements, the task has been easier and require only proper and logical data inputs. The design outputs shall be verified to check for the compliance of obtained values with the stipulated limits.

In addition, the PDGs may solicit additional measures for the effective performance requirements. These could demand for suitable geotechnical properties (bearing capacity, settlement limits etc.) for the intended use of the land for roads as per relevant standards and specifications.

Ground Improvement and Other Requisites

In ports, while roads are constructed over the marshy tidal area, it requires a pre-sub-soil investigation to design suitable ground improvement method before the actual road pavement construction is taken up. The geo-technical investigations normally aim at finding out requisite information, which include but not limited to; depth of soft clay, grain size distribution, clay content, undrained shear strength, initial void ratio, compression index, coefficient of consolidation, unit weight of clayey sub-soil etc.

Deep deposits of soft clay is found all along the coastal and delta areas of the country where Ports come up. Therein, road alignments pass through marine clay sub-soil and conventional construction of roads over such marine clay sub-soil deposits may lead to failures due to very low shear strength and very low permeability of sub-soil. Hence provision of ground improvement measures becomes essential to achieve the required bearing capacity and tolerable total and differential settlements, especially in case of flexible pavements. If the depth of clay layer is moderate (upto 3 m), then it can be removed and replaced by soil having good shear strength. But where the depth of sensitive clays is larger, it becomes essential to adopt ground improvement techniques to achieve the required bearing capacity and tolerable total and differential settlements. Accordingly, different methods of ground improvement may be designed, viz., (1) Use of Geosynthetic Basal Reinforcement below the Road Pavement and (2) Use of Stone Columns(granular material compacted in-situ in long cylindrical boreholes).

The basal reinforcement acts in a manner similar to rigid layer and helps to distribute the embankment load on to the subsoil evenly. Typical Cross section of an embankment is given in the next figure 1.

There are additional requisites also, significant during the development stage and are inclusive within a detailed guidelines. It has to be noted that the primary requirement is that top level for all roads within the Port area shall be the same as that of the terminal yard. Roads within the container yard will generally be a part of the yard, specifications for will be mentioned in the initial guidelines such as ‘the container and stock yards are being provided with Interlocking Concrete Pavements (ICP)’. The other items that may need attention include:

a) Geometric Design of roads within yard- These are normally done as per IRC and MORTH specifications
b) Road markings (Lane, Road Edge, Directional Arrows, etc.)- These are normally done as per IRC and MORTH specifications
c) Road side barriers, fixed type or removable type- These are normally done IRC and MORTH specifications and the choice of type shall depend on the overall yard area design and traffic movement planning that needs to be done
d) For the drainage in the area, the specifications, if specifically stated under ‘Utilities’ shall be followed or shall be adequately designed

Comparison of Flexible and Rigid Pavement

Conceptually, when comparing a flexible and a rigid pavement alternate, the same design life should be considered. However, the comparison of pavement alternates with different design lives for the situation is also being followed as an extended comparative process. In such cases, the periodic upkeep adjustments during different stages of the pavement with relatively shorter life to extend its life should also be counted for economic comparison by way of total transportation cost approach. The intention is to determine during the ‘Detailed Project Report’ phase itself, which alternate pavement design life is the most cost effective. Flexible pavements and rigid pavements can be compared on different parameters. Simple analysis uses only two parameters; cost of construction and carbon footprints.

![Figure 1: Typical Cross Section of an Embankment with Basal Reinforcement](image)
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During the pavement design and construction, it is very important to analyse the present situation with all the factors that have an impact on future structure. Firstly, it is necessary to consider the needs of users and the environment which include features of the existing terrain, weather conditions, operating conditions and the traffic load. Based on that, techno-economic analysis can be carried out with the final selection of adequate pavement structure. With significant investments made on port roads, cost economics is to be treated as very essential and with an integral approach.

**Comparison Based on Cost Economics**

Generally, the major factor in deciding the type of the pavement in design is the initial cost, i.e., investment. Thus, planners often think that the flexible pavement is cheaper than the rigid pavements, which in fact, may be contrary to the results of ‘Life Cycle Cost Analysis’ as many researchers perform cost analysis of pavements. Initial cost of rigid pavement is high but by considering serviceability life of rigid pavement, it is found in many cases that it is economical than the conventional flexible pavement. Construction cost for rigid pavements on weak soils may be cheaper than cost of flexible pavements, in contrast to what is generally thought. However with the strength increase in sub grade the flexible pavement costs and rigid pavement costs get closer. With increasing petroleum product prices, the cost of bituminous pavements will be even higher. Hence, rigid pavement should be openly considered in choosing the pavement types associated with a realistic cost analysis of pavement performed by reasonable estimates. The normally adopted approach, Life Cycle Cost Analysis (LCCA) for economic analysis of pavement investments is deliberated further.

The appropriate solution for economically beneficial pavement type, bituminous or concrete pavement, is calculated by carrying out Life Cycle Cost Analysis (LCCA). Life-Cycle Cost Analysis (LCCA) is an economic analysis used to evaluate the cost-efficiency of alternatives based on the reliable economic analysis methods such as Net Present Value (NPV) concept. It is essential to evaluate the abovementioned cost aspects in order to obtain optimum pavement life-cycle costs. Life cycle cost analysis (LCCA) is a strategy that considers costs all through an advantage’s lifecycle including investment, operation, maintenance and disposal. LCCA adjusts beginning monetary investment with the long term expense of owning and operating the road asset. LCCA methodology involves the following steps:

1. Estimate the initial construction cost.
2. Estimate maintenance cost.
3. Estimate road user costs
4. Determine life-cycle cost

The procedure involved is simplified in the figure 2.

**Need for Cost Analysis and Inferences from Some Studies**

In case of developing countries, like India, there is a shortage of funds required for new infrastructure projects; both for construction and more significantly for their maintenance and repairs. Decision making in planning and design of roads will impact the need of future operation and maintenance activities. Road authorities of all around the world are finding and innovating ways to cope with the high cost of road network maintenance, the increasing demands of road users and the changing traffic type and volume. In such scenario, it is imperative that cost analysis, as above, are carried out and the right option on techno-economic considerations are adopted. While construction costs or initial investment costs are worked out, the possible estimate for maintenance phase is also computed and based on these together, a long term strategy by optimal selection of type of pavement and its design are worked out.

Reviews have shown there are vital inferences from research based studies which can be enumerated as guiding factors in choice of appropriate pavement for a given scenario. The featureist observations from some studies are given below while further studying the related exercises are recommended for further strengthening of the analysis. Factors that help to chose the pavement suggest:

- Flexible pavements show wider range of variation in cost with respect to design parameters of traffic and soil CBR
- The overall variation in cost of rigid pavements is comparatively small
- The design of a rigid pavement is highly influenced by the occurrence of small number of heavy axle loads
- The fatigue life of a rigid pavement is prone to small changes in the stress ratio which can happen with a small increase of the loading along the axle load axis
- It is observed that flexible pavements are more economical for lesser volume of traffic

**Combination Pavements**

Case studies show that, during operations, the ship cargo loads meant for import or export, are carried by heavy trucks which converge as they go for entry/exit at port gates and result in increased traffic volume. It is imperative that these roads stressed under heavier concentration of loads are meticulously designed to satisfactorily cater to the heavy commercial traffic with higher axle loads. Many times, the functional requirements may demand for a bituminous
black topped road pavement, but the flexible pavement may fall short to provide required design life. In such scenario, combination pavements; with cement concrete structural layers, surfaced with bituminous layers might be an option. Design recommendations for the proposed pavement structure primarily may include a Pavement Quality Concrete (PQC) provided over the DLC layer and will preferable have Plain mild steel dowel bars with Deformed steel tie bars. The layer may consider also having bi-directional reinforcement(minimum temp).

In order to functionally complement the above structure with a black top, a bituminous wearing course of Concrete (BC) or Stone Matrix Asphalt (SMA) with mix design using Polymer Modified Bitumen (PMB) and proper interface/interlayer provisions (stress relief/crack retarding layer on the concrete pavement).

A typical cross-section of the recommended combination pavement structure is further Table 2.

Concluding Remarks

From the ongoing discussions, it may be inferred that, for port roads, in general, rigid pavement is economical than flexible pavement. This is more conspicuously inferred that, for port roads, in general, rigid pavement is economical than flexible pavement. This is more conspicuously rigid pavement is more economical than flexible pavement. When comparing total cost of pavement life span rigid pavement will be about 20 % higher than the rigid pavement after 20 years.

4. Initial cost of rigid pavement is higher but when comparing total cost of pavement through life span rigid pavement is more economical than flexible pavement.

5. However, in case of roads where stage construction is possible and adopted, then flexible pavement could prove cheaper than rigid pavement. Also, when soil subgrade is of good quality and traffic is also not very heavy, flexible pavements can be more economical. But, these aspects might be helpful only while designing the secondary or tertiary roads of less importance within the port road network.

6. In cases of areas where soil subgrade is weak and/or drainage conditions are also difficult to maintain at desired level of performance, rigid pavement can be a good choice.

7. Initial cost of rigid pavement (concrete pavement) is reduces by replacing cement by fly ash at some percent, through a proper design. One may explore using other alternatives, as feasible.

However, notwithstanding the above, the use of life-cycle cost analysis is recommended by making realistic inputs.

An interest rate based on current financial data should be used. For initial construction costs, the designers should use thicknesses generated for flexible and rigid pavement designs using the recommended/applicable design input values and methodology developed by standards/guidelines by agencies like IRC.

References:

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2) The Overseas Coastal Area Development Institute of Japan, Technical Standards and Commentaries, Part III, Facilities, Chapter 6 ‘Port Transportation Facilities’
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6) Flexible Pavement versus Rigid Pavement (Prof.Satish Chandra, NBM&CW September 2017)
10) Guidelines for The Design of Flexible Pavements(Fourth Revision, 2018, IRC)
11) Port and Industrial Pavement Design with Concrete Pavers - Second Edition,2020, ICPI,USA

Table 2: Cross-Section for Combination Pavement in the Area of Entry/Exit Gates of Ports

<table>
<thead>
<tr>
<th>Layer</th>
<th>Thickness/Provision</th>
</tr>
</thead>
<tbody>
<tr>
<td>BC with PMB 40 (Optional)</td>
<td>40 mm Annexure 1</td>
</tr>
<tr>
<td>SAMI (IF BC Overlaid)</td>
<td></td>
</tr>
<tr>
<td>Pavement Quality Concrete</td>
<td>250 mm</td>
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<tr>
<td>Polythene Sheet</td>
<td>125 μm</td>
</tr>
<tr>
<td>Dry Lean Concrete</td>
<td>100 mm</td>
</tr>
<tr>
<td>Granular Sub-base</td>
<td>500-600 mm, as per profile / Levels</td>
</tr>
<tr>
<td>Bi-Axial Geogrid(100 kN/m X 100 kN/m)</td>
<td>--</td>
</tr>
<tr>
<td>Screening/ Coarse Sand Layer</td>
<td>200-300 mm</td>
</tr>
</tbody>
</table>
Motor Graders
More Robust & Tougher

Buyers of motor graders including rental agencies are opting for manufacturers who assure them higher productivity and minimum cost of operation and maintenance of their machines. As a base equipment used in road construction, the demand for motor graders remains firm. And with the Union Road Transport Ministry planning to construct 12,000 kms of highways this fiscal, demand will be more for the higher capacity graders of 140 hp to 200 hp as they will cover more areas in lesser time. However, the lighter units will also be in use, especially by the small hirers and sub-contractors.

Says Puneet Vidyarthi, Brand Leader, Case India, “Case motor graders are customized for tough mid-mining projects and for large road projects. They are powered by our reliable FPT engines that come in variable horsepower and deliver maximum performance with optimal fuel consumption in all working conditions. They are extremely versatile and can be used in multiple projects. Our Case 845B and 865B models, for instance, provide an exceptional mix of power, precision, and fuel efficiency. They have an ‘A’ frame of the robust and rigid drawbar, which is also very durable as its larger wear surface provides a longer life, while the externally driven circle is easy to clean and better protected in case of shocks. Consistency of controls and response of hydraulic operations with the ability to make small and precise adjustments in the blade position, ensure better productivity.”

Easy access to the engine compartment enables daily service checks for quick and efficient maintenance of equipment. Heavy duty components like auto transmission, efficient hydraulics for higher machine durability, air-conditioned cabins with good visibility, a unique trip meter on operator dashboard that continuously monitors the fuel consumption, number of hours operated, and operating temperatures, are the other features of the CASE 845B and 865B motor graders.

Vidyarthi informs that Case motor graders have a unique moldboard ranging from 12 to 14 ft, which is recommended as per the application requirement and the strata where it will be used. Since it is hydraulically controlled, the operator can adjust the pitch of the angle of the moldboard from the comfort of the air-conditioned cabin - thus saving time. Secondly, the multi-radius moldboard ensures that the maximum amount of material is rolled off in each pass, which increases productivity, as the number of passes are reduced.

“Since the long stretches of road projects will require assured availability of machines with quick servicing, our motor graders are fitted with ‘Site-Watch’ telematics (electronic indicators connected to the
operator dashboard) to provide real-time information on the operations, safety and service alarms. Site-Watch enables the owner and fleet manager to remotely monitor the machine for data regarding the working status of the machine, including fuel consumption, location, alarms for servicing and maintenance etc, so that we can maintain our machines well on time, as we believe that timely servicing and maintenance will extend the working life of our graders and reduce their downtime for greater availability at all times."

He adds, “Motor graders being capital intensive machines, we give our customers’ loan extensions and warranty support, especially in unprecedented situations like the Covid-19. We offer our customers optional extended warranties on major components so that they can use the machines more confidently, plus they have CASE’s assured back-up and support throughout the machine’s lifecycle. For fleet owners, we offer maintenance contracts with a dedicated service team which is available at site to ensure our machines’ uptime. We have a wide dealer network and a good stock of spare parts at key locations for ready supply. In fact, we are delivering parts and undertaking servicing - even in these challenging times – while adhering to all the safety norms.”

Sanjay Saxena, Senior VP & Head of HE BU, Sany Heavy Industries India, informs that Sany India is offering its higher capacity 17-ton, 170 hp motor graders for construction of highways and roads, while the company’s SAG 200-hp machine is being used for both mining and road projects. “Both the machines, due to their high-powered engines, deliver high productivity. Their power to weight ratio, superior quality components sourced from reputed suppliers, such as transmission from ZF, axles from Kessler and Meritor, and engines from Cummins has enabled us to position our machines strongly in the market and enhance their value. We are also offering the 9-ton, 120 hp motor grader SAG 200, which is powered by Dongfeng Cummins Engines and are providing rippers and dozers as optional attachments for our graders.

Saxena informs that, Sany India motor graders come with both manual and automatic transmission. Quality output is delivered through their superior blade down force and drawbar pull, and a three-dimensional operator seat provides better visibility. Further we are in the process of launching an automated grading system that will augment the productivity and performance of the machine in terms of quantity and quality of grading. It is pertinent to mention here that, our graders are adaptable to latest automatic levelling systems. The result is a combination of precision and speed which together ensures efficient use of machines. He further adds, “It is pertinent to mention here that technology plays a vital role to increase the productivity of work. Right from the basic switching of the machines to the IOT, there are many different technological advancements done in the machines. For instance, IOT enablement of the machines is aimed at capturing the run hours, machine location, technical parameters of the machines, alarms etc. This is a milestone of sorts in improving customer engagement”.

Speaking about their commitment and support system, he adds, “It has been our constant endeavour to work closely with our customers to understand their project needs and design our machines to suit their requirements. Likewise, our wide-spread dealer network and trained service professional ensure fast deliveries of spare parts and support across the country.”
LiuGong manufactures motor graders of 150-180-220-250-280 hp. The higher capacity (220-hp onwards) are imported from its Chinese manufacturing facility. LiuGong India has recently begun manufacturing 180-hp graders at its Pithampur facility. It was earlier manufacturing CLG 414, 150-hp motor graders indigenously, with tyres from local manufacturers and engines from Cummins.

He informs that their LiuGong’s centralized warehouse for stocking spares ensures timely delivery of parts to customers and dealers for its graders and other equipment, while product support is provided by over 23 dealers pan India. LiuGong conducts training programs for its dealers and key customers for effective operation and maintenance of their equipment, which are supported by key supplier partners. The company offers extended warranties and annual maintenance contracts so that contractors can commit the quality output from the resources engaged and get good returns on their investments.

According to Adarsh Gautam, Head Sales & Product Support-Road Construction Equipment Division, Action Construction Equipment Ltd. (ACE), the company is looking to expand its product portfolio for application in smaller roads, especially PMGSY projects. ACE is currently catering to the longer stretches of road construction that require higher capacity graders such as their AG 176 that has a heavy 15-ton operating weight as compared to competing machines that are of 12 to 13-ton operating weight.

ACE motor graders are powered by 173-hp Cummins 6BTA5.9 turbo-charged diesel engine with high torque that enables better performance of the graders, giving higher productivity. Says Gautam, “Productivity is high due to the higher drawbar pull of 9450 kgs and blade down force of 7140 kgs. The graders’ higher operating weight gives better traction and load for all kinds of surface application. ACE graders are rugged, robust and strong due to their engine, operating weight, drawbar pull and blade down force. The productivity of our Grader is around 200 cum per hour with an average fuel consumption of 11-14 ltrs/hr.”

“ACE graders have a unique feature of adjustment of the moldboard through hydraulic cylinders. The blade position can be set by the operator automatically from within the cabin, leading to uninterrupted work. Rock grade heavy-duty 14x25, 20 PR tyres give better grip and longer life on any kind of surface. As already mentioned, the 173-hp Cummins 6BTA5.9 turbo-charged diesel engine is incorporated into the ACE graders, which make them one of the best in class in terms of fuel efficiency,” says Gautam.

Product improvement and product development is a continuous process at ACE with the company working incessantly to meet the needs of the customer. Understanding the need of the hour and to keep up with the modernization of road making equipment, ACE provides the option...
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of Telematics to help machine owners remotely monitor and supervise the various functional parameters of the machine and remain updated of its health for timely maintenance so that the machine gives optimum performance. Gautam informs that the company will be adding a few more features in the telematics system in the BS4 model, which will benefit customers even more.

“Product support and customer satisfaction is not only of prime importance at ACE, it is in fact, our biggest strength and pride. ACE has over 100 sales and service locations across India and we are (usually) able to provide same day response. Similarly, high priority is accorded to the ‘real needs’ of our customers, be it with respect to product features, maintenance or support.

Apart from this we come up with various seasonal financing schemes to benefit our customers. We are currently running a ‘Monsoon Scheme’ on financing our backhoe and road-making segment of machines,” he informs.

Through expansion of the smaller highways. Though the higher capacity 170-200 hp graders will only be viable for greenfield expressway projects, however, the bulk of the work will still be done with <150HP graders as these are much more viable. Post Covid-19, the importance of low fixed costs (EMI/capital investment) has gotten even more engrained in the minds of the contractors and we are anticipating higher demand for our G90 motor grader. This is a sub Rs. 50 lakh product and does 75-80% percent work of the 140 hp motor grader. We see demand in this category going up, post the monsoon season."

Mahindra is presently offering two motor graders - the RoadMaster G75 with a 79 hp engine and the G90 which comes with a 91 hp engine. While the G75 is designed for PMGYS/rural roads and district roads, the G90 is specifically designed for state highways and NH expansion projects.

Says Joshi, “To deliver higher profitability to our customers, we have optimized our product performance and its owning and operating cost to give one of the lowest per cubic meter grading cost amongst all other motor graders being sold in India. Today, the operators and site conditions in India are not suitable for automation, hence, we are holding back from automation for the time being till the eco system becomes even more advanced, by which time, the technology would also have evolved and become more cost-effective.”

To deliver lower cost of operation, Mahindra’s graders are powered by the company’s in-house manufactured Mahindra DTEC engine. “The same engine family caters to many of our high HP international tractors, which work with the same “low speed high torque” requirement. Based on lakhs of hours of testing for performance, we are bringing to our customers graders that provide higher productivity and lesser fuel consumption. In fact, the G90 probably delivers the lowest fuel consumption per unit productivity at an average of about 8-9 liters per hour, amongst all other motor graders sold in India today.”

To ensure higher availability of its motor graders, they are supported through Mahindra’s ‘Remote Care.’ This is available with its backhoe loader EarthMaster and most of the above features are already incorporated in its upgraded telematics unit DIGISENSE

“Mahindra motor graders are supported by 1-year unlimited hours warranty,” says Joshi. “Other manufacturers are offering a warranty capped at 2000 hours. We are also offering customized product options, several finance options, and even rental services to corporates through our rental arm “Hello Machine”. We also offer extended warranties covering all major aggregates and have extended the warranties for products under warranty in the “lockdown phase”. From an aftermarket, product support perspective, we have initiatives like “Parts Express” (parts delivery to doorstep at certain locations), Saral Seva (dedicated on-demand service), and many other specific initiatives apart from the industry’s standard aftermarket practices.”
The durability and life of the machine’s undercarriage impacts the operating cost of the machine and has a significant effect on the overall production cost and productivity of the machine. The expenses on account of the undercarriage are next to that of the fuel used in bulldozers and excavators and track type loaders. In fact, the operation cost incurred on account of the undercarriage is affected by the machine’s configuration, its operation and maintenance. So, the undercarriage cannot be ignored as it supports the machine’s entire weight and must perform efficiently in the roughest of terrains and counter abrasive materials like silica and sand, which is more abrasive than rock.

Machine configuration during purchase: Equipment manufacturers offer their machines with various types of undercarriages specific to the machine’s applications. Hence, the indenter should consider factors like material hardness, fragmentation, operating conditions, and productivity during the machine’s configuration. The choice of undercarriage should also be based on the materials handled by the machine. These have been categorized under four broad categories:

- High impact and High abrasive
- High impact and Low abrasive
- Low impact and High abrasive
- Low impact and Low abrasive

Moderate impact and moderate abrasive is also a factor to be considered.

Operator skills: A skilled operator will keep a constant watch on the machine and listen to any sounds made by it. The present generation machines have sophisticated electronics and hydraulics, and a comfortable operator cabin. While these are intended to reduce operator fatigue and improve productivity, the operator must continue to observe and sense the stress being put on the machine parts that are bearing the entire load of the machine running on tough underfoot conditions. The operators must be trained to inspect any abnormal sound during operation, and undertake daily physical inspection of all visible parts such as track shoes, links, bushings, idlers, bottom rollers, top rollers, roller guards, sprockets and fasteners for any crack, bend, looseness, wear and tear, etc.

Maintaining correct sag of track chains: Certain amount of sag as recommended by the machine manufacturer has to be maintained in track chains to minimise friction. Too much tension in track chain leads to spalling, faster wear of all mating components, and even higher fuel consumption because of excess load. Sometimes, a track chain with a recommended sag may get tension due to packing of material; hence, it is advised to adjust the track tension based on the working condition.

Undercarriage Life of Machines

Importance of Operational & Maintenance Practices

A machine’s undercarriage needs special attention as it supports the entire machine weight and performs in tough terrains, over obstacles and abrasive materials like silica, sand etc, says Bhaskarudu Peddakotla.
Too loose a track chain can cause derailing, or the chain may pop out from the sprocket. There may be unusual impacts between parts with possible chipping and spalling. Natural wearing of links, rollers, idlers, sprockets etc. over a period of time causes loosening of the track. So, this must be observed and measured as per the defined procedure and adjusted to the recommended limit. Track tension or sag adjustment is a simple process in any machine; it can be done by pumping or releasing grease from a cylinder provided for the job. Ensure that there are no leaks in the grease seals. The machine’s inspection must include checking the sag at defined intervals.

Cleaning: Mud accumulation or packing of soil/sand in between moving parts is a common phenomenon in machines. The packing of sand or soil not only increases the track tension but also acts as a grinding media between the parts and causes rapid wear and tear. It also puts an extra load on the powertrain of the machine, which leads to excess fuel consumption and shortens the life of the clutch packs. So, regular cleaning of the machine is necessary to minimize wear and tear of the undercarriage parts.

Speed: Operating the machine at high speeds accelerates the wear and tear rate of the undercarriage components. It is a tendency of the operators of dozers and track loaders to reverse the machines at a very fast speed. This is because during forward travel, they have to push the material with a full width of blade (in case of a dozer) or the bucket of material to be loaded (in case of a track type loader). Hence, due to the natural resistance of the material, the machine cannot move forward with great speed.

Due to the design configuration of the undercarriage (idlers are in the front, sprockets are in the rear, and the track sag is on top), the contact area between bushing and sprocket teeth will be more during reversing (about 75%) as compared to forward travel (about 25%). Greater the contact area, more the friction and ultimately more wear and tear of the parts. Operators also tend to run the machine at a high speed when moving from one location to another. Hence, they must be educated on the impact of speed on the life of the undercarriage.

Negotiating curves: Sharp turns and counter rotations increase contact stresses between components, causing damage and faster wear of components. Operators need to slow down the machine when negotiating turns.

Machine orientation: This applies particularly in sidehill operation during which the machine will have more load between the link sideface and roller flange, which causes accelerated wear of both link and roller. This type of wear and tear reduces the link width (unlike rail wear during operation in flat ground) which leads to further link wear. The operator should therefore keep changing the position of the machine by turning it on both sides.

Avoid unwanted travel: It is advisable to have a mobile maintenance facility for oil filter change, fuelling, washing etc., nearer to the machine, rather than taking the machine to a garage. This way, a lot of travelling can be avoided, and the wear and tear reduced. Operators tend to run an empty machine at a high speed.

Maintenance: Preventive maintenance through condition monitoring is critical for extending the life of the undercarriage. The maintenance team must keep a checklist of all components of the undercarriage. Based on operating conditions, regular inspection intervals should be decided in consultation with the machine manufacturer’s service representative. The machine should be cleaned thoroughly before inspection and proper tools are to be used for taking the measurements. No approximations should be entered in the check sheet. Once the inspection is completed, the data must be analysed on the wear and tear of each and every component and an assessment made on the expected residual life. This not only helps in meticulous planning of parts and servicing but also minimizes machine downtime. Sometimes, an inspection may reveal that the sprocket needs to be changed twice for every change of track link assembly. A systematic approach will help in maximizing component life and minimizing downtime of the machine.

In addition, the maintenance team must also analyse the operational data obtained from the machine reports such as travel percentage of the machine, speed of travelling etc., based on which the team can prepare an action plan to bridge the gaps and accordingly advise the operator.
Ready Mix Concrete in India
With Quality Assurance

Ajit George, QA/QC Incharge Geomix Concrete, Wayanad Kerala

Ready mix concrete (RMC) is the first choice for projects requiring concrete. The term ‘ready mix’ is used to describe a process where concrete is pre-made at a plant and delivered in batches to job sites. It is a convenient and efficient tool for construction as it is ready to be cast, which saves time and money. Each batch of ready mix concrete is especially created as per the requirements of the contractor. It is prepared with basic ingredients like water, cement, and aggregates and once delivered to the construction site it must be used right away.

Almost all mixing plants have the same basic layout such as an aggregate storage, cement / pozzolan storage, batchers (aggregate batching, cement batching, water and admixture batching), dust collection system, feed system, and mixers like a truck mixer or a stationary mixer. Modern technology has enabled operation of ready-mix plants from a remote location, wherein a batch operator uses videos and computers to control crucial areas of the plant.

The process of producing concrete in measured batches is called batching. Every ready-mix concrete plant uses this process to produce concrete. Weigh Batching uses a hopper and a scale to batch all the dry materials. The scale gives a read-out of the weight of material in the hopper. Due to its consistent nature, water can be batched by weigh batching or volumetric batching.

Concrete mixer trucks deliver the pre-made mixture and there is no further preparation required as it’s ready to go at the job site. Ready mix concrete is the preferred choice for both small and large projects and is the ideal solution in any site condition.

**Layout Terms**

**Control Room:** The ‘brain’ of the plant that calculates and sends out the exact measurements required for each sub-station, allowing them to create the specified mix.

**Aggregate Bins:** This is where all the different types of aggregates are stored. Here, the exact amount of the required materials is weighed, and then carried via a conveyor belt to the mixing station and ready to be mixed together.

**Cement Silos:** Here, the cement is stored, weighed, and transferred to the mixing station, ready to be mixed with the aggregates.

**Water & Additives:** Once water is added to the dry ingredients, the wet concrete mix starts to form. Additives are also added for extra strength, faster curing, or better workability.

**The Mixing Station:** Here, all the dry ingredients are mixed together with the wet ingredients until the correct consistency is formed.
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The Discharge Point: The mixture is discharged and loaded into the back of the drum mixer, which rotates to keep the consistency correct while being transported to the job site.

Market View
RMC is being preferred over traditional concrete due to ease of use, greater convenience, economy, and better quality. Furthermore, wastage reduction, low inventory costs, and efficient utilization lead to a lowering of the overall project costs, which in turn will augment the product demand in the coming years. Key benefits of RMC are low labour and supervising cost, consumer awareness regarding eliminating wastage associated with bulk handling, and consistency in quality. An increase in big projects is spurring consumption of RMC because of its high quality and ease of use. The time constraints placed upon infrastructure development projects in the urbanized economies is creating a high demand for ready-made concrete mixes. Also, RMC has reduced shrinkage, cracking and volume change.

On the downside, concrete’s limited timespan between mixing and going off means that ready-mix should be placed within 90 minutes of batching at the plant. This feature acts as a restraint in the market.

Economic Impact on Industry
An RMC manufacturing company will have the following departments:
- Managerial Board
- Quality Assurance & Quality Control Department
- Operating Department
- Coordination Department
- Mechanical Department
- Electrical Department

Companies with a capacity to produce a minimum quantity of 2000 m$^3$, will need qualified and experienced staff, besides local labourers, so that all the departments work smoothly and in coordination with each other. In a highly competitive industry, companies cannot afford to compromise on the quality and quantity of their production.

Quality Control & Quality Assurance
In India, RMC was introduced about two decades ago. However, due to lack of proper manuals, higher initial costs as compared to conventional site mixed concrete, high initial investments for installation of automatic batching plants, and lack of awareness, the RMC industry faced an initial setback. Today, the RMC industry is growing as rapid urbanization with demand for multi-storied housing, large offices and commercial complexes, and other Real Estate projects are placing increasing demand for good quality concrete to make the structures safe and durable.

The QA/QC team is headed by a QA/QC Manager, who is the key person in the decision making process. He is assisted by a QA/QC Incharge whose job is to co-ordinate and implement the quality guidelines and test procedures for the batching plant. The Incharge is assisted by at least two QA/QC engineers who are responsible for physically conducting the tests of the incoming raw materials and the final RMC. They are required to check the proper functioning and calibration of all the equipment and carry out daily or weekly quality monitoring as per the proposed model. The QA/QC Incharge will take decisions on the assignable causes noticed during the monitoring phase.

At least four lab technicians should be employed per plant to carry out the sampling and testing. The fire performance of building products has always come under close scrutiny — and for good reason. The structures where people live and work must be safe. It is for this reason that building codes exist as a means to safeguard life and private and public welfare by regulating the design, construction practices, quality of construction materials, location, occupancy and maintenance of buildings and structures — all of which should be monitored and tested as per the code standards.

The work under a tender should be executed strictly in accordance with the constructional and material requirements defined under the specifications. The contractor must acquaint himself with these specifications to determine his contractual obligations for the work. The conditions of these specifications will be binding on the contractor and no deviation will be permissible, unless specifically approved by the consultant or project-in-charge, in writing. In the absence of any detailed specifications, the latest Indian standard specifications and code of practice will become applicable. Wherever the codes and specifications are absent, then the same will be governed by sound engineering practices and the decision of the project-in-charge / consultant in matters of interpretation etc., will be deemed as final and binding on the contractor.
Tests and relative IS codes for concrete related materials:

**Cement Tests IS:4031 – 2019**
- Determination of fineness by dry sieving
- Determination of fineness by specific surface by Blaine air permeability method
- Determination of soundness
- Determination of consistency of standard cement paste
- Determination of initial and final setting times
- Determination of compressive strength of hydraulic cement (other than masonry cement)
- Determination of compressive strength of masonry cement
- Determination of transverse and compressive strength of plastic mortar using prism
- Determination of heat of hydration
- Determination of drying shrinkage
- Determination of density
- Determination of air content of hydraulic cement mortar
- Measurement of water retentivity of masonry cement
- Determination of false set
- Determination of fineness by wet sieving
  Method of chemical analysis of hydraulic cement

**Coarse & fine aggregate - Tests IS 2386**
- Methods of test for aggregate for concrete particle size and shape
- Methods of test for aggregate for concrete estimation of deleterious materials and organic impurities
- Methods of test for aggregate for specific gravity, density, voids, absorption & bulking
- Methods of test for aggregate for Mechanical properties.
- Methods of test for aggregate Soundness
- Methods of test for aggregate measuring mortar making properties of fine aggregates.
- Methods of test for aggregate for alkali-aggregate reactivity
- Methods of test for aggregate for petrographic examination

**Fresh Concrete - Tests IS:1199 – 2018**
- Sampling of fresh concrete
- Determination of consistency of fresh concrete
- Determination of density of fresh concrete
- Making and curing of test specimens
- Tests on fresh self-compacting concrete
- Determination of setting time of concrete by penetration resistance
- Determination of water soluble and acid soluble chlorides in mortar and concrete
- Analysis of freshly mixed concrete

**Hardened Concrete - Tests IS:516**
- Compressive, flexural and split tensile strength of hardened concrete
- Properties of hardened concrete other than strength
- Making, curing and determining compressive strength of accelerated cured concrete test specimens
- Sampling, preparing and testing of concrete cores
- Non-destructive testing of hardened concrete
- Determination of drying shrinkage and moisture movement for concrete samples
- Determination of creep of concrete cylinders in compression
- Determination of modulus of elasticity
- Wear Resistance
- Pull out test for bond in reinforced concrete

- Method for determination of Portland cement content of hydraulic cement concrete
- Determination of water soluble and acid soluble chlorides in hardened mortar and concrete

**Benefits of Ready Mix Concrete**
- As it is made by professionals, RMC is of high quality and therefore more sustainable and durable.
- RMC is made by using consistent methods and precise equipment. Materials are tested before usage and the whole process is monitored by professionals to maintain the quality of the mixture.
- As the mixture is made by mechanized operations, the speed of delivery is faster, which means that the whole process of construction will be faster.
- Also, there will no delays in erection and dismantling of the site batching plant.
- Wastage of the ready-mix concrete is less. Proper mixing and better handling of the mixture reduces the consumption of concrete by approx 10%. So, it will reduce the cost of the project.
- Less consumption will reduce production and result in less pollution of the environment.
- As RMC plants use bulk cement, the ratio of dust in cement is reduced.
- Since the mix is more durable, there is increased service life.
- Due to atomized processes, RMC requires less human labour, thus reducing the risk of human errors.
- Fuel (diesel/petrol) usage is less; this reduces the cost of the project, besides reducing noise and air pollution.
- It is very helpful in sites in congested areas.

The construction industry is next in line after agriculture in India which accounts for about 11% of India’s GDP, thereby making a significant contribution to India’s economy and providing employment. This is because of the linkages that the sector has with other sectors of the economy. About 250 ancillary industries such as cement, steel, brick, timber and building material are dependent on the construction industry. A unit increase in expenditure in the construction sector has a multiplier effect with a capacity to generate income as high as five times.
Polish precaster inBet launches second Carrousel Plant

The state-of-the-art carrousel plant for production of double walls and lattice girder floors is supplied by precast plant and machinery manufacturer EBAWE and its sister company Progress Maschinen & Automation of the Progress Group.

Strength through Diversification

Though precast accounts for 50% of the company’s activities, inBet, since its beginnings, has shown strength through diversification: In addition to its precast activities, approximately one third of its business activities is focused on metal products; 10% on ready-mix concrete; in addition to a few other business activities such as reinforcement mesh and trusses. Though the company’s regional stronghold traditionally is in greater Kolbusz near Gdansk, it covers a radius of roughly 100kms, including Gdansk, Sopot, Gdynia and Rumia, and also markets its precast products to the south of Sweden.

Precast Products for Leading Building Projects

The company covers a wide portfolio of precast products, including lattice girder floors, double walls, stairs, and balcony elements. With the high quality of its products and increased production capacities, inBet has been able to offer precast elements to leading building projects all over the region, including both single multi-storey residential buildings as well as complete residential areas. Well known reference projects include the Osiedle City Park Project, the Hynka Housing Development and the Old Tenement Quarter.

Good Reasons for a new Investment

In 2020, inBet’s latest investment - a brand new Made in Germany carrousel plant for double walls and lattice girder floors - started its production. The company’s strategy for setting up a new precast factory was twofold: on the one hand, inBet’s aim was to increase its filigree production output, and on the other hand, it became possible for the company to introduce new products like the double wall, which offers numerous advantages.

The company had realized that more and more building companies and developers were looking to create buildings with precast elements due to the lower construction times and reduced need for workers. It, therefore, set up a new factory whose key elements represent a modern and highly efficient filigree and double wall production.
The pallet turning device is the new centerpiece for the carousel's plant double wall production.

The Pluristar by Progress Maschinen & Automation is an automatic stirrup bender, straightener and double-bending machine in one. It was perfectly integrated into the new EBAWE carousel plant.

The Pluristar: Automatic Stirrup Bender & Straightener in One

In addition to a state-of-the-art carousel plant by Eilenburg based EBAWE, inBet made use of the ability of Progress Group to provide turnkey and tailor-made solutions for their precast factory, not only in the field of precast concrete technology but also in the field of reinforcement and steel processing. Consequently, inBet also included the Pluristar by Progress Maschinen & Automation into the new investment.

The Pluristar is an automatic stirrup bender, straightener, and double-bending machine in one. It can process wire diameters of 6 – 16 mm. The heart of the Pluristar is the combined straightening system consisting of a roller straightening unit and a rotor straightening unit. This unique combination allows the flexible manufacture of stirrups, straight rebars and rebars with large bends using a single machine. Depending upon the given product, the suitable straightening unit is fully automatically inserted. The wire is changed fully automatically or manually, as needed. The Pluristar can also be equipped with a 3-D bending system - enabling not only 2-dimensional, but also 3-dimensional stirrups.

Key Elements of the new Carousel Plant

- The horizontal and vertical compacting process enables the best possible concrete compaction at low noise levels, thus creating a better work environment.
- In production halls with limited space, the combined plotter and pallet cleaner enables two working processes to be carried out in one single working station.
- The plotting machine allows for a reduction of human errors and high precision of the produced precast elements.
- Progress Group’s in-house software and master computer ‘ebos’ ensures the best possible overall control of the carousel plant. Among others, ebos offers functions such as automatic pallet assignment, print modules for work sheets, label and report printing modules, etc.

Filigree slabs allow for quick and tailor-made floor slab production and installation.

In the Osiedle City Park Project shorter construction times were reached with the use of precast elements.

The Old Tenement Quarter project of inBet also used numerous precast products.
**Importance of Strong Partnerships**

inBet CEO Maciej Jęczmyk is highly satisfied with his second experience with EBAWE and Progress Maschinen & Automation. He sums up his cooperation with the Progress Group companies as follows: “We were very satisfied with our interaction with EBAWE and Progress in 2017, and also now, for our new factory, we decided again for the same machinery partner. It was easy for us to work together, and we very much appreciate the support, trust and reliability of EBAWE and Progress.”

inBet is confident that the second carrousel plant, which is already running in two shifts, will be as successful as the first carrousel plant.

---

**Compressors**

**MARK Compressors launches new range of Piston Air Compressors across segments**

MARK Compressors, a part of Atlas Copco Group in India, has launched two new product variations in their Piston Compressor range: the Ironwind series and the Bluewind series. Equipped with a robust cast iron pump and a simple plug-and-play solution, the products are very reliable and durable for the Indian market needs.

Key industry segments such as automobile, tyre retail industry, fuel stations, woodworks, small-scale industries, micro, small and medium scale business units, and independent professional businesses, where pneumatic and air applications come into play, will benefit from these compressed air solutions.

The new products with advanced engineering and innovativeness will enhance customers’ productivity, reduce energy consumption, and offer higher uptime and reliability. An upgraded cooling system keeps the heat emission in check during long working hours. Designed in a compact ‘tank’ format, the products are on wheels which makes them portable. This feature is especially handy for projects with frequently changing workstations. The products will be available in various sizes, displacement, and power options, ranging from 1.5HP to 10HP, which are completely customizable as per respective industry requirements.

Andy Prabhakar, General Manager - Brand Portfolio at Atlas Copco, said, “We are proud to offer solutions that have been created with very durable parts, ensuring efficiency of performance, along with services backed by timely maintenance. The new range of air compressors with the cast iron piston technology is a result of Mark’s continued commitment to offer products that are very user-friendly, reliable and efficient. The company ensures that the products and parts are easily available and serviceable across the country through our channel partners.”

The company also offers a prominent range of air compressors including oil-injected screw air compressors, refrigerant dryers, line filters, air receivers and piping solutions.
With best compliments from:

ConMechAuto Consultants India Pvt Ltd.,
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Works: Plot # 217/1, Sector 3, Phase 2, IDA,
Cherlapally, Hyderabad-500 051.
Phone: 040-27261465

Email: sales@cmac.co.in
www.cmac.co.in
Fixed-width screeds are frequently used when large widths need paving without joints. This was the case for a new section of the B75 in Hamburg, called the Wilhelmsburger Reichsstrasse. This major road runs alongside the railway tracks for a distance of about 4.6 km. Bundling two large traffic routes in one place means that both the town and its inhabitants gain space, and the noise pollution of the busy road is reduced. Paving was performed by a SUPER 2100-3i-type tracked paver. This Highway Class paver of the state-of-the-art Dash 3 generation from VÖGELE is the machine of choice for a great many highway projects.

**VÖGELE’s new SB 300 Fixed-Width Screed ensures top quality paving**

The new SB 300 Fixed-Width Screed from VÖGELE demonstrated its benefits right from the start during a project to lay a major road. It processed complex materials such as porous asphalt and stone mastic asphalt in large widths, with convincing results.

SB 300 Fixed-Width Screed: top-quality paving

For some time, both contractors and operators have had yet another reason to use the SUPER 2100-3i to work without joints in large widths: the SB 300 Fixed-Width Screed. In combination with the SUPER 2100-3i, it can pave a maximum width of 13 m. The asphalt paving work in Hamburg almost reached this limit: the binder and wearing courses were paved in a width varying between 10.5 and 12.5 m. To ensure that the carriageway resists deformation, one part was made of stone mastic asphalt, whilst a 2.2 km-long section was completed in porous asphalt to reduce noise.

When processing materials, compaction performance and the floating behaviour of the screed are of key importance. Both are highly dependent on the correct tamper setting. With hydraulic tamper stroke adjustment for the new fixed-width screeds, VÖGELE delivers an innovation which allows tamper stroke to be adjusted at the push of a button. It can be selected between 4 and 8 mm, the important point being that 4 mm is recommended for thin layers such as binder and wearing courses, whilst a stroke of 8 mm is recommended for thick base courses.

Perfectly organized highway construction: in addition to VÖGELE machine technology, job site logistics to guarantee continuous paving were another key factor in the success of this project.
Current state of the art: the SB 300 and SB 350 Fixed-Width Screeds from VÖGELE integrate numerous innovations; among other things, these reduce set-up time and accelerate paving when pave widths vary.

Hydraulic bolt-on extension increases variability to 2.5 m

Together with his paving team, construction manager Martin Iske from contractors Kemna Bau managed all the challenges faced on the B75 in style – due, among other things, to the latest screed technology from VÖGELE: “The new screed is very rigid; the immaculate evenness makes this clear. The new variability is another feature to highlight - paving without joints would have been impossible without it.” Iske is referring to a key new feature on the SB 300: the hydraulic bolt-on extension. This extension to the outside of the screed can be extended hydraulically – by 1.25 m on each side, so a total of 2.5 m. This enables VÖGELE to combine the advantages of its extending screeds with those of the fixed-width screeds: a high degree of flexibility plus maximum evenness. On this large-scale job site, the Kemna Bau paving team pushed this advantage, too, almost to the maximum: pave width varied by around 2 m.

Other practical new features increase efficiency

The SB 300 can be combined with several VÖGELE pavers, from the SUPER 1800-3i to the SUPER 3000-3i. It has a basic width of 3 m and a variety of extensions can be used to increase it to a width of up to 16 m. The development team developed the SB 300 together with the SB 350. The latter delivers a pave width of 18 m which can be achieved in combination with VÖGELE’s flagship paver, the SUPER 3000-3i.

Two new/further developments on the SB 300 and SB 350 Fixed-Width Screeds ensure that they are ready for action quickly: the guide and positioning system and the electric screed heating system. Whilst the guide and positioning system helps users fit the extensions correctly, the electric heating system brings the screed to operating temperature more quickly and more evenly than the preceding model.

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Quality without compromise for the major B75 road in Hamburg: the SB 300 Fixed-Width Screed from VÖGELE delivers absolutely premium-quality, perfectly even results and is the hallmark technology of this world market leader.
MST-4 Self-Loading Concrete Mixer
Revolutionising Performance with Ease of Operation

MACONS, a leading manufacturer and supplier of world-class equipment for use in India and for the global construction markets, has introduced its latest MST series of Self Loading Concrete Mixer ‘MST-4’ which is an outcome of the company’s decades of industrial experience, innovativeness, and technical prowess.

Available in the capacity of 2/4 m³, the new series of Self-Loading Concrete Mixer is designed for better control and faster output. It has the biggest in class loading bucket, a comfortable operator cabin, 4-wheel drive and crab steering, which provides traction for gradeability up to 35%.

**Key features of MST-4**
- Bigger fuel tank – fuel efficient design
- Sturdy chassis
- Mixing drum & heavy linkages
- Three-way steering system
- Bigger wheelbase & stability, low turning radius
- Slewing drum arrangement
- Comfortable operator cabin
- Electronic weight batching plant
- Batch report printer
- Battery & fuel tank located inside cabin to prevent damage and pilferage
- 180-degree reversible driving post
- Efficient & reliable after sales services & support approved by leading financiers
- Lower owning and operating cost

**Says Dharmesh Surelia, CMD, Macons Equipments,** "The economic scenario due to the pandemic since the last few months has created many challenges for companies across the world. But we at Macons took the situation as a learning opportunity. We are closely monitoring consumer trends, their requirements and buying behaviour across markets, and are accordingly adapting our business models and product offerings to meet their needs. We have prepared ourselves even better now to cater to future demand with quality products and innovations. We have been engaging our workforce with brainstorming sessions and R&D activities. The result is our recent innovation – the MST series of Self-Loading Concrete Mixer – a gamechanger which will revolutionize performance with its energy-efficient design and ease of operation. That apart, we are on the verge of introducing many new products in the coming months."

"With our proactive approach and astute market foresight, we are striving towards a future in which we envision making the Indian markets thrive with our equipment, while also bringing more value to global projects with our superior quality, high performing products. We believe that the long-term growth drivers for the CE industry will remain robust as the government is taking several initiatives for infra development and the industry will emerge stronger post the pandemic," he adds.

From a modest beginning, Macons has seen an astounding y-o-y growth and is rising swiftly as a leading player in the Indian CE industry, offering its clients high quality products with reliable and timely after-sales services. The company has been credited for introducing many innovative products such as the Compact Concrete Batching/ Mixing plants, Mobile Concrete Batching/ Mixing plants, Self-loading Transit Mixers, Kerb Pavers and Dumpers, all of which are being produced locally.

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Neptune offers Advanced Technology for Concrete Blocks & Pavers

Neptune is offering a concrete block manufacturing plant based on European technology, which gives the desired strength to the product along with various shapes and dimensions. Neptune has also developed in-house Vibration technology to produce various designs of Concrete blocks, Hollow blocks, Interlocking pavers, Kerbstones etc.

Today, concrete block manufacturing is a highly automated process. Concrete block technology is based on the principle of densification of a lean concrete mix to make regular shaped, uniform, and high-performance masonry units. The technology can easily be adopted to suit the special needs of users by modifying the design features such as mix, proportion, water/cement ratio etc. Neptune’s machine-made pavers have a strength of more than M-60, making them the most suitable for use in roads, footpaths, and in areas that have heavy vehicular traffic.

A fineness modulus of combined aggregates of 3.6 to 4mm and coarse aggregates of 6 to 12 mm is recommended. Mix for pavers should not be richer than one part of the cement to six parts of the volume of the combined aggregates.

Neptune’s fully automatic high-tech plant with auto batching system, special design mixer, heavy-duty vibrating press & paver and block handling automatic stacking system, can produce 10,000 to 1,00,000 concrete blocks per day and pavers of 1,000 to 10,000 sqm per day. An electric control panel with process logics and programme has been designed by the company’s experts for the desired qualitative production and smooth operation of the plant. The Auto Synchronized system with Servo motor technology has been developed for controlling the speed up to milliseconds, while the frequency and amplitude can be individually defined, which makes this system highly flexible. The plant’s regenerative power supply increases the energy efficiency of the whole system.

Neptune’s mobile paver manufacturing plant is designed for large road construction projects. Companies that can invest in a captive requirement of pavers at site will save time and energy.

NBM&CW Keeps You Updated With all Aspects of Civil Engineering and Infrastructure Projects. Subscribe Today for Just ₹1,500 per annum.
After a successful stint in the road construction equipment industry, Saumil Shah, one of the promoters of Kaushik Group, has taken a decision to diversify into the concrete equipment manufacturing segment and has set up a company called ‘Kaushik Coninfra’. The company’s focus will be on manufacturing Concrete Batching plants (Stationary & Portable ultra-compact), Canal Paver & Curb Paver. It will later expand the portfolio to include other innovative products.

Says Shah, “At Kaushik Coninfra, our priority is to give the best concrete equipment to our clients, which will bring them more efficiency and productivity at the jobsite, thus helping them to complete their projects on time and within the given budget. We believe in bringing the latest technology products that offer reliable solutions and the required technical expertise to the construction industry in order to build sustainable infrastructure in the country. Meeting customers’ expectations and earning their trust is most important for a brand to get recognition in the industry and get repeat orders.”

Keeping both infrastructure and real-estate project requirements in view, Kaushik Coninfra has launched concrete batching plants in two series: CB & MCB with capacity ranging between 35 M3/H to 180 M3/H.

The company is running training programs for the operators to help them operate the machines efficiently and troubleshoot any problem in order to reduce the downtime of their machines/plants. It is also providing aftersales support and service to their customers.

Adds Shah, “Keeping quality as a top priority, Kaushik Coninfra is focusing on R&D and also looking for technical tie-ups with brands of international repute. Our aim is to contribute to the growth of the country by helping in making it a world class manufacturing hub for both domestic and global markets. Our mission is to lead the world of concrete production by designing and building state-of-the-art concrete construction equipment with the best technology available in the market.”

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Concrete Batching Plant

**Standard Configuration**
- Three / Four Bin System
- Load out Conveyors
- Pan type / Planetary / Single Shaft / Twin Shaft Mixer Type Mixing Unit
- Discharge Conveyor
- Cement Hopper with Screw Conveyor
- High Pressure Jet Cleaner system for Mixer
- PLC + PC based Electrical Control Panel

**Optional Accessories**
- Moisture Probe System (In Sand bin & Mixer).
- Silo Accessories like: Dust collector, level indicator, fluidization pad, pressure relief valve etc.
- Blower system for cement/fly ash loading in silo.

**Advance Control System**
- Fully automatic PLC control system with SCADA for inventory management and different report generation. Any types of faults and errors will be diagnosed by the control system.
- Emergency manual discharge facility
Implications of the Proposed Shear Design Provisions in the Indian Code IS 456

Most of the provisions in the Indian code, IS 456:2000, are based on the experimental investigations on concrete with strengths less than M40. Hence, recently, new equations for the shear strength of RC beams have been proposed for the next revision of IS 456. These equations and their implications in actual design are presented after a brief presentation of the behaviour of beams in shear and comparable provisions in other few notable international codes. A case study of the failure due to inadequate shear design is also provided.

Dr. N. Subramanian

The shear behaviour of reinforced beams has been researched for more than a century and the foundations of knowledge on shear were provided by Mörh in 1909. Reinforced concrete is a composite material and shows non-isotropic mechanical properties, which complicates the formulation of relationships between stresses and strains in the material. Hence, the design recommendations of several codes of practice are based on empirical relations derived from laboratory tests. It has to be noted that in many situations, we are concerned with diagonal tension stress, which is a result of the combination of flexural and shear stress. Hence shear failure is often termed as diagonal tension failure. There may be certain circumstances where consideration of direct shear is important. One such example is in the design of composite members combining precast beams and cast in place to slabs, where horizontal shear stresses at the interface between beam and slab have to be considered. As it is inappropriate to use methods developed for diagonal tension in such cases, we have to resort to the shear-friction concept, which is not yet available in IS 456 (Subramanian, 2020).

It is well known that inadequate shear design is inherently more dangerous than inadequate flexural design, since shear failures are sudden and normally exhibit fewer significant signs of distress and warnings than flexural failures. However, unlike flexural design for which the classical beam theory (“plane sections remain plane”) allows for an accurate, rational and simple design for both uncracked and cracked members, the determination of shear strength of reinforced concrete members is based on several assumptions, all of which are not yet proved to be correct. It is important to realize that there is a considerable disagreement in the research community about the factors that most influence shear capacity.

The main objective of RC designer is to produce ductile behaviour in members, such that ample warning is provided before failure. To achieve this goal, RC beams are often provided with shear reinforcement. Also codes are usually more conservative with regard to shear (by providing larger safety factors) compared to bending (for example in the ACI code, a strength reduction factor of 0.75 is used for shear compared to 0.9 used for flexure-tension controlled). Thus, the design methods and detailing rules prescribed in the codes will result in a strength that is governed by bending failure rather than shear failure, if the member is overloaded.

Although the Indian code on reinforced concrete IS 456 was revised in 2000, only the durability provisions of the code were modified extensively. The design provisions were largely unchanged from the earlier version. Moreover, most of the provisions in the Indian code, IS 456:2000, are based on the experimental investigations on concrete with strengths less than M40. Hence, recently, new equations for the shear strength of RC beams have been proposed for the next revision of IS 456 (Sahoo, 2020). These equations and their implications in actual design are presented after a brief presentation of the behaviour of beams in shear and comparable provisions in other few notable international codes.

Behaviour of Beams in Shear

The mechanism of the brittle type diagonal tensile failure of RC beams with no shear reinforcement (stirrups) is complex and not yet fully understood. The behaviour of beams failing in shear may vary widely, depending on the $a_v/d$ ratio (shear span to effective depth ratio) and the amount of web reinforcement. In very short shear spans, with $a_v/d$ ranging from 0 to 1, develop inclined cracks joining the load and the support. These cracks, in effect, change the behaviour from beam action to arch action. Such beams with $a_v/d$ ratio of 0 to 1 are termed as deep beams. Beams with $a_v/d$ ranging from 1 to 2.5, develop inclined cracks and after some internal redistribution of forces, carry some additional loads due to arch action. These beams may fail by splitting failure, bond failure, shear tension or shear compression failure (see Fig. 1).

![ Typical crack pattern (Source: ACI- ASCE committee 426, 1973) ](a) Typical crack pattern (Source: ACI- ASCE committee 426, 1973)
In slender shear spans, having \(a_1/d\) ratio in the range of 2.5 to 6, the crack pattern will be as shown in Fig. 1(a) and (b). When the load is applied and gradually increased, flexural cracks appear in the mid-span of beams which are more or less vertical in nature. With further increase of load, inclined shear cracks develop in the beams, at about 1.5\(\sqrt{d}\)/2\(\sqrt{d}\) distance from the support, which are sometimes called primary shear cracks (Subramanian, 2013). The typical cracking in the slender beams without transverse reinforcement, leading to the failure involves two branches. The first branch is slightly inclined shear crack, with typical height of the flexural crack. The second branch of the crack, also called secondary shear crack or critical crack, initiates from the tip of the first crack at relatively flatter angle, splitting the concrete in the compression zone. It is followed by a tensile splitting crack (destruction of the bond between steel reinforcement and concrete near the zone of support), as shown in Fig. 1(a). Depending on some geometric parameters of the beam, the critical crack further extends in the compression zone and finally meets the loading point, leading to the collapse of the beam. The failure is by shear-compression [see Fig. 1(c)], due to the crushing of concrete, without ample warning and at comparatively small deflection. The nominal shear stress at the diagonal tension cracking at the development of the second branch of inclined crack is taken as the shear capacity of the beam.

**Case Study: Partial collapse of Wilkins Air Force Depot in Shelby, Ohio**

It is interesting to note that the shear provisions of the ACI code were revised after the partial collapse of Wilkins Air Force Depot in Shelby, Ohio, in 1955 (Feld and Carper 1997). At the time of collapse, there were no loads other than the self-weight of the roof. The 914 mm deep beams of this warehouse did not contain stirrups and had 0.45 percent of longitudinal reinforcement (Feld and Carper 1997). The concrete alone was expected to carry the shear forces- and had no shear capacity once cracked.

The beams failed at a shear stress of only about 0.5 MPa, whereas the ACI Code (1951 version) at the time permitted an allowable working stress of 0.62 MPa for the M20 concrete used in the structure. Experiments conducted at the Portland Cement Association (PCA) on 305 mm deep model beams indicated that the beams could resist a shear stress of about 1.0 MPa prior to failure (Feld and Carper 1997). However, application of an axial tensile stress of about 1.4 MPa reduced the shear capacity of the beam by 50 percent. Thus, it was concluded that tensile stresses caused by the restraint of shrinkage and thermal movements caused the beams of Wilkins Air Force Depot to fail at such low thermal shear stresses (Feld and Carper 1997). This failure outlines the importance of providing minimum shear reinforcement in beams. It has to be noted that repeated loading will result in failure loads which may be 50 to 70 percent of static failure loads (ACI-ASCE committee 426, 1973).

**Behaviour of Beams with Shear or Web Reinforcements**

When a beam with transverse shear reinforcement is loaded, most of the shear force is carried by the concrete initially. Between flexural and inclined cracking the external shear is resisted by the concrete \(V_{zc}\), the interface shear transfer, \(V_{s}\), and by the dowel action \(V_d\) (See Fig 2). The first branch of shear cracking of the beams with transverse reinforcement is typically same in nature as that of beams without transverse reinforcement. The shear crack in this case also involves two branches. The formation of the second crack and the corresponding load may be assumed to be the same. After the first inclined crack, redistribution of shear stresses occurs, with some parts of the shear being carried by the concrete and the rest by stirrups, \(V_{s}\). Further loading will result in the shear stirrups carrying increasing shear, while the concrete contribution remaining constant.

The presence of shear reinforcements restricts the growth of diagonal cracks and reduces their penetration into the compression zone. This leaves more uncracked concrete in compression zone for resisting the combined action of shear and flexure. The stirrups also counteract the widening of cracks, making available significant interface shear between the cracks. They also provide some measure of restraint against the splitting of concrete along the longitudinal reinforcement, thus increasing the dowel action also.

With further loading and opening of cracks, the interface shear, \(V_{s}\), decreases, forcing \(V_{s}\) and \(V_d\) to increase at an accelerated rate, and the stirrups also start to yield. Soon the failure of the beam follows either by splitting (dowel) failure or by compression zone failure due to combined shear and compression.

It is clear from the above description that once a crack is formed, the behaviour is complex and dependent on the crack location, inclination, length, etc. Hence it is difficult to develop a rational procedure for design, and past provisions in National codes are based on partly on rational analysis and partly on experimental data (ACI-ASCE committee 426, 1973).

**Provisions in International Codes**

The Canadian code sectional design model for shear is more accurate and based on extensive tests. Using the test results Prof. Collins, Prof. Vecchio and associates of the University of Toronto developed the Modified Compression Field Theory (MCFT), and a simplified version of this is adopted in the Canadian code CSA S23-2014. This method considers the combined efforts of flexure, shear, axial load (compression or tension) and torsion. This method is also adopted in the AASHTO LRFD and the current Australian code AS 3600:2018.
The design shear strength of concrete, \( \tau_c \), is governed by several factors such as compressive (tensile) strength of concrete, longitudinal reinforcement ratio \( p_r \), shear-span to effective depth ratio, type and size of coarse aggregates used in concrete, size of beam (size factor), size of coarse aggregates used, effect of axial force, and type of cross-section (Subramanian, 2013).

**Indian code IS 456:2000**

The current version of the Indian code, IS 456:2000 suggests an empirical formula based on the experimental research of Rangan 1972, which considers the grade of concrete and longitudinal reinforcement ratio, and presented in the form of a table (Table 19 of the code) and the concerned equation is given only in SP 24:1983 as below:

\[
\tau_c = \frac{0.85}{(0.85 A_s / (6.89 f_y) - 1) / (6.89 f_y)}
\]

Where \( \beta_a = \left( \frac{0.85 A_s}{(6.89 f_y)} \right) \), whichever is greater.

The factor 0.8 in the formula is for converting cylinder strength to cube strength, and the factor 0.85 is a reduction factor similar to partial safety factor \( (1/\gamma) \), according to SP 24:1983. The values given Table 19 of the code may also be approximated by the equation:

\[
\tau_c = 0.64 \left( \frac{1000 A_s}{b d} \right)^{1/3} \left( \frac{f_c}{25} \right)^{1/3}
\]

It is interesting to note that these equations and the Table 19 in the code served well till now, because they resulted in very conservative values of shear stress (Subramanian, 2013). Recent study on shear strength of flyAsh-incorporated recycled aggregate concrete beams, showed that the Eqn. (1) of IS 456: 2000 can predict the shear capacity of most of the beams irrespective of the concrete types, with adequate safety as shown in Fig. 3 (Sunayana and Barai, 2020). It also found that the prediction of IS 456 provisions is over-conservative.

![Figure 3: Comparison of experimental database with shear strength prediction of IS-456 (Source: Sunayana and Barai, 2020)](image)

**American code ACI 318:19**

As per the present version of the ACI 318:19 code (as per Table 22.5.5.1), \( V_r \) for non-prestressed beam is given by Eqn. (3) as given in Table 1 (after applying the strength reduction factor for shear of \( \phi_s = 0.75 \) and converting \( f_s' \) to \( f_s \), by using the approximate relation \( f_s' = 0.85 f_c' \); although more precise coefficient R to convert cylinder strength to cube strength is \( R = 0.76 + 0.2 \log (f_c') \). Subramanian, 2013). In addition, it has to be noted that the ratio of standard cylinder strength and standard cube strength is about 0.8-0.95; higher ratio is applicable to HSC.

**Eurocode 2 (EN 1992-1-1:2004)**

Previous research has shown that the expression, which is a function of one third power of concrete compressive strength, truly represents the shear strength (Subramanian 2003). Hence, the latest Eurocode2 (EN 1992-1-1:2004) expression for nominal shear strength as given below, which also considers size effect, and applicable to normal and high strength concretes.

\[
V_n = 0.85 (0.7 f_c') k_1 k_2 (f_s'/25)^{0.33} \frac{(400 f_s')^{2/3}}{d^{0.25}}
\]

Where \( k_1 = 1 \) for aggregate size \( \geq 20 \) mm and \( k_1 = 0.85 \) for aggregate size \( \leq 20 \) mm; \( k_2 = Size\ effect\ factor; \ k_1 = 400 f_s'\) for \( d \geq 400 \) mm and \( k_2 = 1.0 \)

**New Zealand code (NZS 3101-Part 1:2006)**

The New Zealand code (NZS 3101-Part 1:2006), which considers the size of aggregates and size effect is given below

\[
V_n = V_{r, bd} = 0.87 f_{c,k} A_t k d
\]

Where \( \phi_s = 0.75 \), \( f_{c,k} = 0.89 (0.07 \times 10^{1/2}) \)

**Indian Code Provisions in the Proposed Revision**

After applying the material safety factors of 1.15 for steel and 1.5 for concrete, the proposed shear strength equation may be rewritten as (Sahoo, 2020)

\[
V_r = V_{r, bd} = 0.87 f_{c,k} A_t k d
\]

Where aggregate type factor \( \lambda \) has values of 1.0 (normal weight concrete), 0.85 (sand light-weight concrete, and 0.75 (all-light weight concrete), cross-section geometry factor \( \lambda_g \) has values ranging from 0.83 (rectangular/square section) to 0.70 (circular section) and cross-section size factor \( \lambda_s \) has values ranging from 1.0 (\( d < 400 \) mm) to 0.7 (\( d > 400 \) mm). Note that in Equation (7) the shear stress is now dependent on (1/3) power of concrete strength, whereas traditionally all shear strength is expressed as a function of \( \sqrt{f_{c,k}} \).

As circular sections are not usually adopted for beams, Eqn. (7) could be simplified as

\[
V_r = 0.87 f_{c,k} A_t k d
\]

These proposed rational shear design provisions for one way shear with shear reinforcements have been compared with other international codes of practices (Sahoo, 2020). These provisions have also been validated with more than 1000 shear tests available in ACI-DAS database, and found to be conservative with very low values of standard deviation and coefficient of variation (Sahoo, 2020). Comparing eqn. (7) with Eqn. (3) of ACI 318:2019 shows that both of them have the same format. In a recent paper, Dolan (2020) has also illustrated the effects of the changes in the ACI 318:2019 code provisions on shear strength.

Though the format of equation (7) is similar to the ACI code [Eqn. (3b)] and the values of aggregate type factor \( \lambda_g \) are also similar, ACI 318-19 adopts a different cross-section size factor \( \lambda_s \) of (Bažant, et al. 2007)

\[
\lambda_s = \sqrt{\frac{2}{1+0.004d}} \leq 1\text{f}
\]
Shear Strength of RC Beams

Perhaps the proposed equation for $\lambda_s$ is adopted from NZS 3101 (Part 1):2006 or BS 8110-1:1997.

A comparison of the values based on IS 456:2000 provisions and the proposed Eqn. (7) are given in Table 2. Note that the IS 456:2000 provisions are up to a percentage of reinforcement of 3%, but the proposed Eqn. (7) is valid up to 2% only. Also, IS 456:2000 suggests same values of M40 to grades greater than M40 also. From this table, it is clear that the proposed Eqn. (7) allows a higher shear stress than those of current IS 456:2000 provisions for concrete grades M30 and above and the increase is higher, as the grade of concrete increases, for all percentages of reinforcement.

It is also important to note that the shear strength values calculated using the proposed Eqn. (7) are very conservative compared to the values calculated using other international codes (Subramanian, 2013; Sahoo, 2020). For example, the shear strength predicted by the proposed Eqn. (7) will only be 45% of the ACI code value, though they are of the same format. It is because large shear stress values for high strength concrete, which may exhibit brittle behaviour than normal strength concrete! Will it not be better if this trend is reversed?

### Maximum Shear Stress

Shear strength of beams cannot be increased beyond a certain limit, even with the addition of closely spaced shear reinforcement. It is because large shear forces in the beam will produce compressive stresses causing crushing of the web concrete strut (SP 24:1983). To avoid such failures, an upper limit on $\tau_{\text{c,max}}$ is often imposed by the codes. IS 456:2000 imposes a maximum shear stress, $\tau_{\text{c, max}}$, which should not be exceeded even when the beam is provided with shear reinforcement, as given below

$$\tau_{\text{c, max}} = 0.1\sqrt{f_{ck}}$$

Where $\gamma$ is a safety factor = 0.85. Converting it to cube strength, we get

$$\tau_{\text{c, max}} = 0.85[0.83\sqrt{0.8f_{ck}}] = 0.631\sqrt{f_{ck}}$$

Using the above equation, the $\tau_{\text{c,max}}$ values for different grades of concretes are calculated and presented in Table 20 of IS 456:2000.

The ACI 318 code (Clause 22.5.5.1.1) also has a similar limit of $\tau_{\text{c,max}}$, as $0.42\sqrt{f_{ck}} = 0.29\sqrt{f_{ck}}$ with $\sqrt{f_{ck}} \leq 8.3$ MPa. (It has to be noted that this value is only 46% of IS code value). The British code, BS 8110, limits the maximum nominal shear stress to 0.8 $\sqrt{f_{ck}}$ or 5 MPa whereas the New Zealand code NZS 3101, as per clause C7.5.2 limits, it to 0.16 $f_{ck}$ (approximately corresponding to a diagonal compression stress of 0.36 $f_{ck}$) or 8 MPa, whichever is smaller.

A new expression for $\tau_{\text{c,max}}$ based on comparison with the provisions of other international codes has now been suggested (Sahoo, 2020). After applying the material safety factor for concrete of 1.5, it is rewritten as

$$\tau_{\text{c, max}} = 0.1f_{ck} \text{ for } f_{ck} \leq 80 \text{ MPa}$$

Comparing Eqn. (9b) with Eqn. (10) shows that the maximum permitted shear stress is no longer a function of $\sqrt{f_{ck}}$ but directly proportional to the compressive strength of concrete. This change was done in order to better visualize crushing failure of concrete strut in terms of its compressive strength, $f_{ck}$, rather than $\sqrt{f_{ck}}$. It has to be noted that the NZS 3101-1:2006 code also limits the maximum shear stress in terms of $f_{ck}$.

A comparison of this proposed equation with that of the current IS 456 provision (Table 20 of the code) is given in Table 3. From this table it may be observed that the proposed equation allows less maximum shear stress for concretes below Grade M40 and allows more values for high strength concrete, which may exhibit brittle behaviour than normal strength concrete! Will it not be better if this trend is reversed?

<table>
<thead>
<tr>
<th>Concrete Grade</th>
<th>M25</th>
<th>M30</th>
<th>M40</th>
<th>M50</th>
<th>M60</th>
<th>M70</th>
</tr>
</thead>
<tbody>
<tr>
<td>IS 456 Eq.7</td>
<td>0.29</td>
<td>0.31</td>
<td>0.29</td>
<td>0.33</td>
<td>0.30</td>
<td>0.36</td>
</tr>
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<td>IS 456 Eq.7</td>
<td>0.29</td>
<td>0.31</td>
<td>0.29</td>
<td>0.33</td>
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<td>0.36</td>
</tr>
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<td>IS 456 Eq.7</td>
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<td>0.33</td>
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<td>0.36</td>
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<td>0.29</td>
<td>0.33</td>
<td>0.30</td>
<td>0.36</td>
</tr>
</tbody>
</table>

### Influence of Axial Tension/compression on Shear Strength

The following equation has been proposed for the percentage reduction in the concrete shear stress due to the influence of axial tension as (Sahoo, 2020)

$$\delta = 1 - \frac{12P_d}{4f_{ck}} \geq 0$$

The IS 456 code already has the reduction factor for compression as (clause 40.2.2 of IS 456)

$$\delta = 1 + \frac{3P_d}{4f_{ck}} \geq 0$$

It has to be noted that in the proposed reduction factor for IS 456, two different values (12 and 3 respectively) are used in the numerator based on Eqs. (11) and (12) of the NZS 3101-1:2006 (Eqs. 10.14 and 10.15 of NZS code). But in the ACI code, for both tension and compression same reduction factor is used with difference only in the sign, which is easy to remember and use.

### Minimum Shear Reinforcement

As per clause 26.5.1.6 of IS 456:2000, minimum shear reinforcement should be provided in all the beams when the calculated nominal shear stress $\tau_s$ is less than half of design shear strength of concrete, $\tau_{\text{c,design}}$, given in Table 19 of the code. The minimum stirrup to be provided is given by the following equation.

$$\frac{A_s}{b_d} \geq \frac{0.4}{0.87f_{ck}}$$

Where $A_s$ = Area of cross- section of transverse reinforcement, and $v_s$ = stirrup spacing along the length of the member. Note that the code restricts the characteristic yield strength of stirrup reinforcement to 415 N/mm².

Tests conducted by Roller and Russell on HSC beams indicated that the minimum area of shear reinforcement as per Eqn. (13) was inadequate to prevent brittle shear failures because cracking occurred through the aggregates and due to this the contribution from aggregate interlock was minimum; they also suggested that the minimum shear reinforcement should also be a function of concrete strength (Roller and Russell 1990). Hence, the current version of ACI code provides the following equation for minimum shear reinforcement.

$$\frac{A_{s,min}}{b_d} \geq \frac{0.055\sqrt{f_{ck}}}{f_{yr}} \geq \frac{0.35}{f_{yr}}$$

Where $f_{yr}$ is the yield stress of the concrete.
Note that the above equation provides for a gradual increase in the minimum area of transverse reinforcement, while maintaining the previous minimum value. In seismic regions, web reinforcement is required in most beams, because the shear strength of concrete is taken equal to zero, if earthquake-induced shear exceeds half the total shear (Wight, 2015).

Now a different equation for the minimum shear reinforcement is proposed for the future revision of IS 456, as follows (Sahoo, 2020)

\[ \frac{A_{s,min}}{b_{wy}} = \text{Max.} \left( \frac{0.06 f'c}{f_{cy}} \cdot \frac{0.4}{f_{cy}} \right) \]  

(15)

By comparing Eqns. (14) and (15) it is seen that both are similar, with only slight change in the coefficients. But, only when the value of \( f_{cy} \) is greater than 45 MPa, the first term in the right hand side of Eqn. (15) will govern. Also the coefficient 0.4 in the second term in the right hand side of Eqn. (15) is less than the coefficient 0.45 (i.e., 0.4/0.87) in the current version of the code, leading to less area for minimum shear reinforcement up to \( f_{cy} \) less than 56 MPa. Hence it will be better to modify 0.4 as 0.45 in Eqn. (15), as in the present version of IS 456:2000. In this connection, it is interesting to note that the author compared provisions of international codes against the provision of minimum shear reinforcement in IS 456 and suggested a need to include both \( f_{cy} \) and \( f_{cy} \) (Subramanian, 2010). This reference also contains suggestions for minimum tension, maximum flexural reinforcement for beams, and upper limit on area of shear reinforcement. Now IS 456 (clause 40.4) allows only up to 415 MPa for characteristic strength of reinforcement, even if higher strength reinforcement is used. But ACI 38-19 [Table 20.2.2.4(a)] allows up to 550 MPa for shear reinforcement. Hope the proposed IS 456 will also include the use of higher strength reinforcement, with strength up to 550 MPa.

**Upper Limit on Area of Shear Reinforcement**

If the area of shear reinforcement is large, failure may occur due to the shear compression failure of concrete struts of the ‚truss model‘ prior to the yielding of steel shear reinforcement. Hence, an upper limit to the area of shear reinforcement corresponds to the yielding of shear reinforcement and shear compression failure of concrete simultaneously, is necessary. Based on literature it is suggested to have the following expression (Subramanian, 2010):

\[ p_{s,max} = 0.16 \left( \frac{f_{cy}}{f_{w}} \right) \]  

(16)

Other Suggestions to the Proposed IS 456 Shear Provisions

Fiber reinforced concrete is being used increasingly in India in several applications due to its advantages. It would have been better if a factor is included in Eqn. (7), using which shear strength of fiber reinforced concrete beams could also be calculated (ACI 544.4R-18, Subramanian, 2007).

The author proposes to remove Clause 40.5 of IS 456 which allows the designer to consider enhancement of shear strength near the support. Clause 40.5 of IS 456 also recommends reducing shear reinforcement near the support, due to this enhanced shear strength-this will increase the vulnerability of shear failure and hence not advisable, especially in seismic zones (Subramanian, 2013).

**Conclusions**

Inadequate shear design is inherently more dangerous than inadequate flexural design, since shear failures are sudden and exhibit fewer significant signs of distress and warnings than flexural failures. The determination of shear strength of reinforced concrete members is based on several assumptions. Design codes are usually more conservative with regard to shear (by providing larger safety factors) compared to bending and provide design methods and detailing rules which will result in a strength that is governed by bending failure rather than shear failure. If the member is overloaded. The design provisions of IS 456 were largely unchanged from the earlier 1978 version and are based on the experimental investigations on concrete with strengths less than M40. Hence, recently, new equations for the shear strength of RC beams have been proposed for the next revision of IS 456. These equations and their implications in actual design are presented after a brief presentation of comparable provisions in other notable international codes. It is seen that the proposed equations are tweaked in such a way that they give similar results to that of IS 456:2000 for concrete with strengths less than 40 MPa, and at the same time providing values for concretes up to 80 MPa. These shear strength values are very conservative than those predicted by other international codes (for example, less than 50% of those prescribed in ACI 318-19).

**References**

1. ACI 544.4R-2018: Guide to Design with Fiber-Reinforced Concrete, American Concrete Institute, Farmington Hills, Mich., 18pp.

About the Author:

Dr. N. Subramanian, an award winning author, consultant, and mentor, now living in Maryland, USA, is the former chief executive of Computer Design Consultants, India. A doctorate from IITM, he also worked with the Technical University of Berlin and the Technical University of Bundeswehr, Munich for 2 years as Alexander von Humboldt Fellow. He has 45 years of professional experience which includes consultancy, research, and teaching in India and abroad. Dr. Subramanian has authored 25 books and more than 265 technical papers, published in international/ Indian journals and conferences. He is a Member/Fellow of several professional bodies and a past vice president of the Indian Concrete Institute and Association of Consulting Civil Engineers (India). He is a recipient of several awards including the 2013 ICI - L&T Life Time Achievement award of the Indian Concrete Institute, Tamilnadu scientist award, and the ACCE(I)-Nagadi best book award for three of his books. He has also been a reviewer for many Indian and international journals.
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