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1. To restore the desired status to the Structural Engineer in construction industry and to create awareness about the profession.
2. To define Boundaries of Responsibilities of Structural Engineer, commensurate with remuneration.
3. To get easy registration with Governments, Corporations and similar organisations all over India, for our members.
4. To reformulate Certification policies adopted by various authorities, to remove anomalies.
5. To convince all Govt. & Semi Govt. bodies for directly engaging Structural Engineer for his services.
6. To disseminate information in various fields of Structural Engineering, to all members.

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- ❇ Rehabilitation of Structures
- ❇ Construction Technology & Management
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- ❇ Non Destructive Testing
- ❇ Bridge Engineering

& Other related branches

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- Page size: A4, Top, Bottom, Left and Right margins: 1", Font: Arial, 10 pt
- Max length of article: 5 pages including tables and figures
- The manuscript should contain the title of article and names, qualifications, designations, addresses and email addresses of the authors.
- The matter should be relevant to the subject and should be organized in a logical flow. It may be divided into sections and sub-sections, if necessary.
- While, sketches and drawings should preferably be in Corel-draw, other appropriate formats are also acceptable. Photographs should be sharp and clear.
- Figures, photographs and tables should be numbered and should have captions.
- Notations, if used, should be clearly defined.
- Article should be sent by email to isse@vsnl.net with a copy to mail@technoesis.co.in

Articles may be reviewed and suitably edited before publication.

Shopping Cum Office Complex With Double Basement Using Composite Structure

Cover Story

Milind Shinde

Owner:
M/S Prabhat Group, 104, Prangan, Vile Parle,
Mumbai – 400 057

Site Address :
Prabhat Construction, S. V. Road, Opposite Daulat Nagar Phatak, Borivali (W), Mumbai - 400 092.

Built – Up Area: 5000 Sq-m

Architect :
Vijay Garodia & Vaibhav & Gauri Shah, Mumbai

Structural Consultants:
Struct Bombay Consultants, Mumbai in collaboration Steelscape Consultancy Pvt. Ltd.

Stage: Lower Basement completed

Planning:

- Commercial cum shopping complex
- Double basement + Six Upper Floors (Floor Ht 14'0")
- Lower basement for car parking with 2 car lift
- Upper basement for shopping
- Ground floor for shopping
- 1st floor upward office.
- Two staircases
- Two car lifts + three passengers lift

Soil Report :

Soil exploration work was done by Safe Cores and Tests and based on this report the recommendations were prepared by Geotech Consortium

See Fig. 1 for bore log

Excavation:

Excavation upto 9 m was required to complete the proposed double basement. Prof. G.B. Choudhary (Emeritus Professor-V.J.T.I.) guided the excavation of double basement. Shoring, to protect the adjacent structure and safeguard the working personnel, was done with 600mm dia. piles 12m in length along the periphery of excavation. Bedrock was encountered at depths between 7.0 m to 8.3 m below the ground level, hence some rock breaking was done with breakers. At road side large open space was available and therefore no shoring piles were provided.

See Fig. 2 for layout of shore pile

See Fig.3 for section and details of pile

See Fig.4 for reinforcement details of piles

Foundation:

- As depth of excavation required is @ 9.0 m. to prevent side collapse of earth, preventing damage to structures on adjoining property and provide for working arrangement 600 dia shore piles @ 700 mm c/c spacing in some portion & 1200 mm in some portions (as per figure - 2) are provided. On road side as open space is more piles are not provided. Piles are designed as a column with lateral force to retain earth. Runner Beam of size 600 X 600 mm is provided over top of piles to make piles behave as retaining wall.
- Type of cement used is 53 Grade OPC conforming to IS-12269
- Minimum Grade of concrete used is M30.
- Retaining wall of 300mm thick is provided in addition to shoring piles with box type water proofing.
- Open foundation is provided for columns as hard strata is available.
- Raft with 300 mm thickness is provided with rock anchor at 1.5 m c/c in grid for uplift due to water pressure. (32 mm Tor anchors anchored in 75 dia. holes & grouted with MCcrete non shrink grout.)
- Box type water proofing done to retaining wall.

Structure:

1) Framed Structure is adopted for the proposed building.
2) Large open space was required for functional purpose. Due to large spans & restriction on beam depth, the structural members have been designed of composite section (Structural steel embedded in Concrete).
3) Slab comprises of profiled steel decking which also acts as permanent formwork to the underside of the concrete slabs spanning between supports beams.

Analysis and design:

1) Analysis was carried out on Staad-Pro software.
2) Design is done using composite section i.e. structural steel embedded in concrete along with required reinforcement. Sample section is shown in Fig.5.

Author : Milind Shinde is a design engineer with Struct Bombay Consultant. He can be reached at : sbcbom@gmail.com

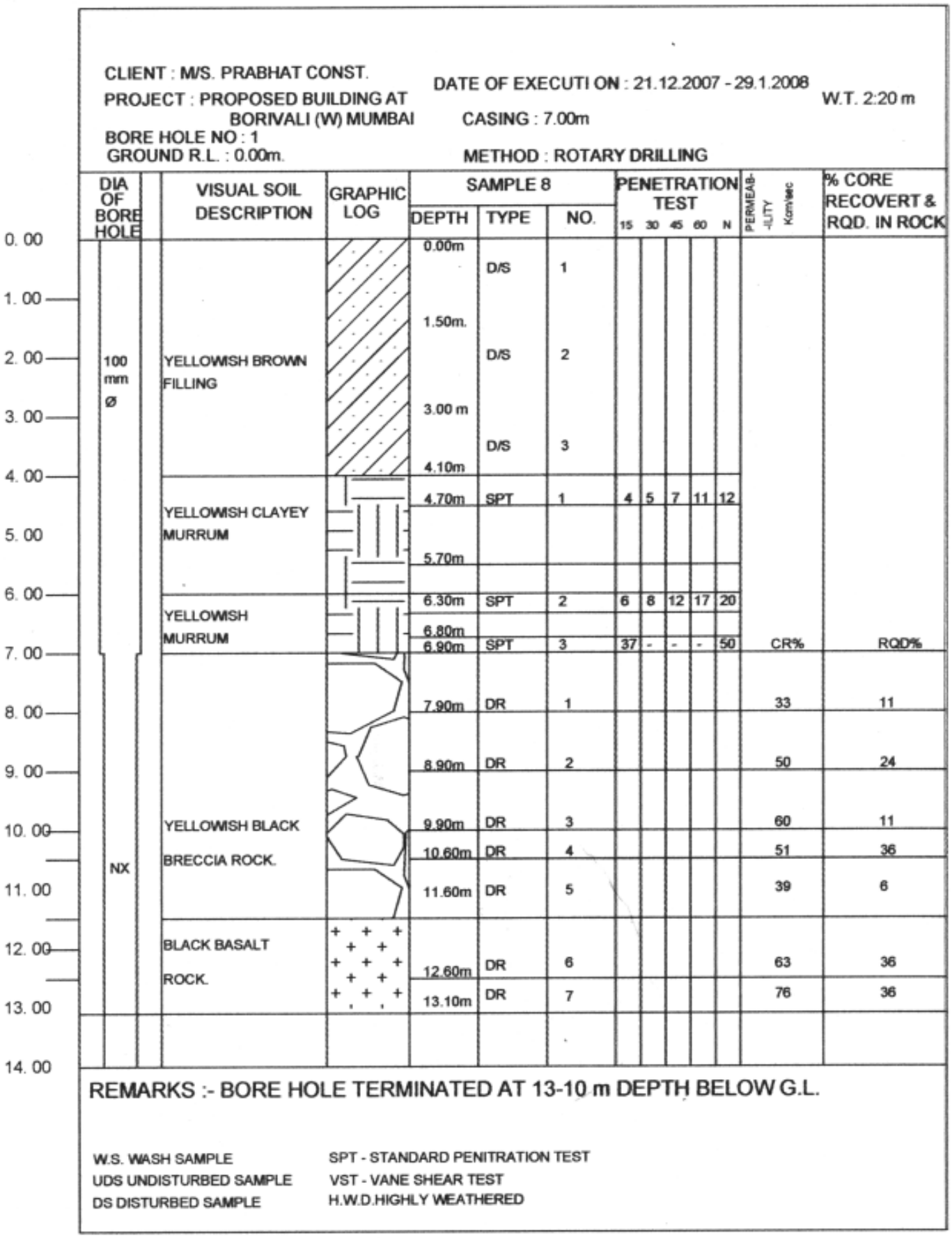


Fig. 1 : Bore Log

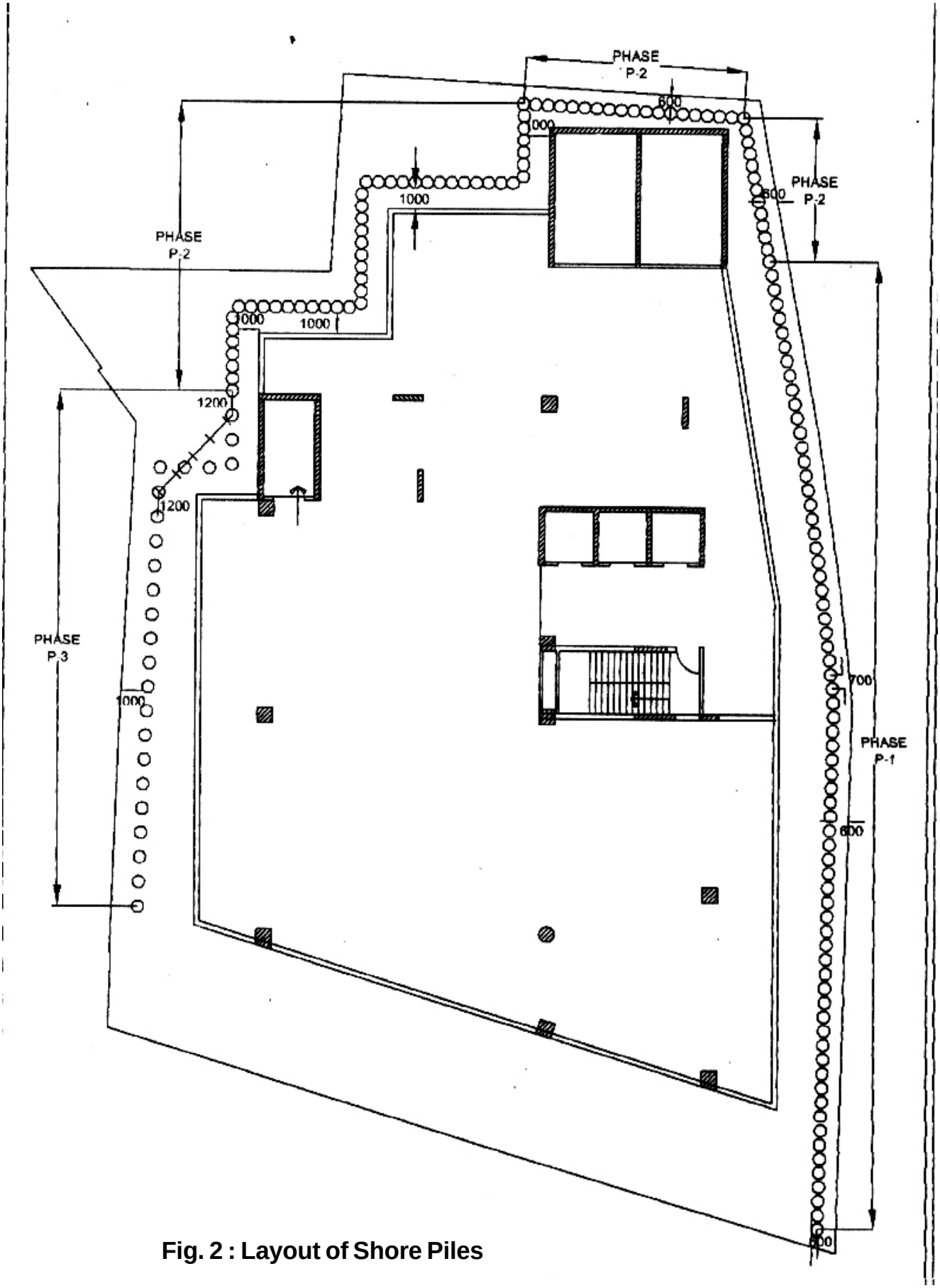


Fig. 2 : Layout of Shore Piles

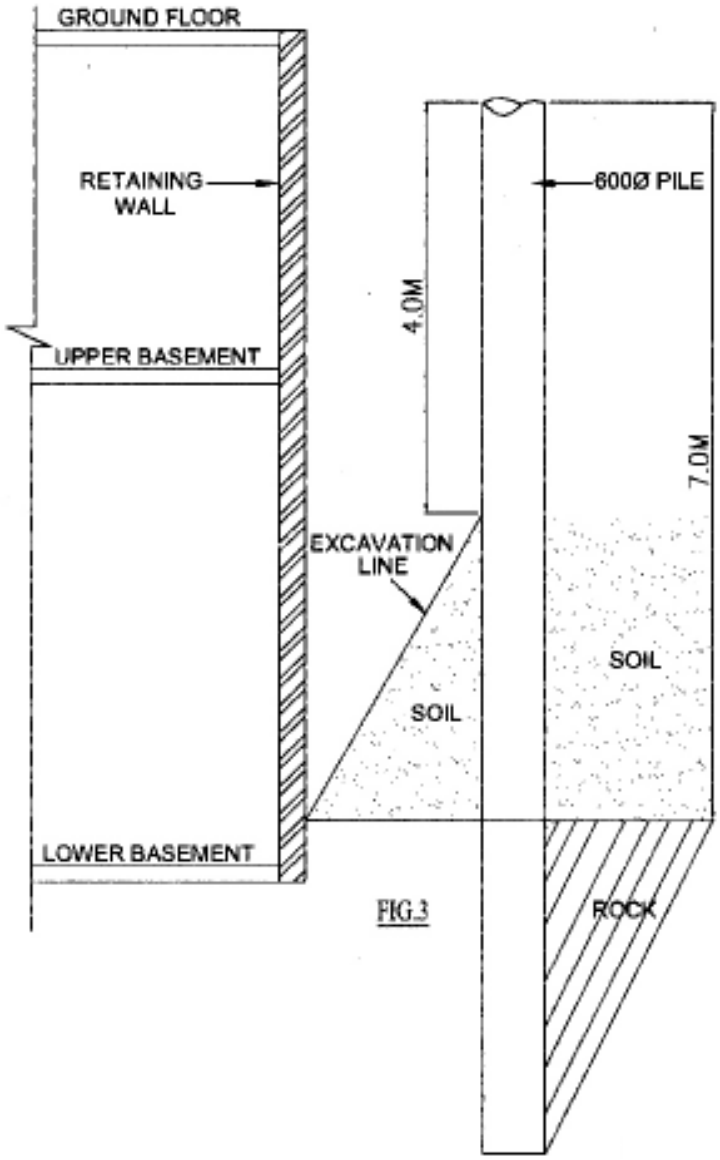
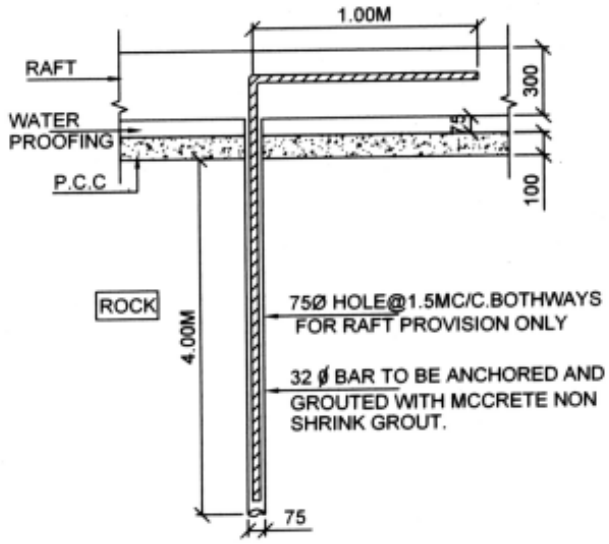


Fig. 3 Pile Section



ROCK ANCHORS @ 1.5m C/C BOTHWAYS IN RAFT PORTION ONLY

Fig. 6

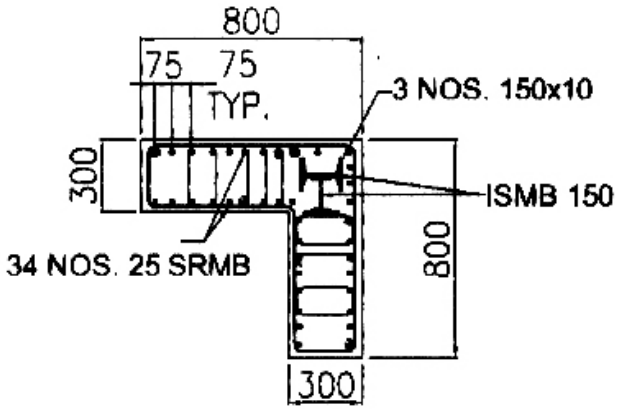


Fig. 4 : Column Details

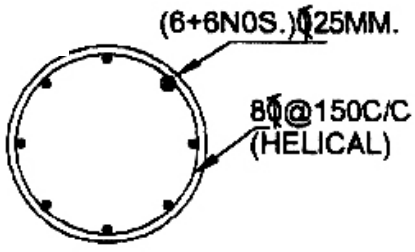


Fig. 5 : Pile Details

PRACTICAL PROBLEMS ENCOUNTERED IN PILE FOUNDATIONS

S. H. Balchandani

Introduction :

Construction of pile foundations requires a careful choice of piling system. Following aspects need to be considered before taking up any piling work:

- Proper soil investigation
- Study of soil investigation report
- Study of characteristics of soil, especially sulphates & chlorides
- Testing quality of sub soil water
- Estimating negative drag
- Selection of grade and quality of cement
- Special considerations, if any, in structural design
- Construction eccentricity
- Pile caps
- Study of provisions of IS codes

This article presents typical cases wherein practical problems were encountered in construction of pile foundations owing to various construction parameters.

Soil Characteristics

Concrete did not set for more than a week in one test pile installed at the site. Detailed investigation showed that concrete had traces of molasis, which had penetrated from surrounding soil. Piling system was eventually modified to suit the site conditions. Finally bored precast piles were provided.

Readymix Concrete

Piling work for bridge was in progress. In one pile, concrete cast in morning did not set even by the next day evening. Work was stopped. Investigations revealed problem in pozzolanic material ratio adopted for readymix concrete.

Vibration in surrounding structures

Conventional cast-in-situ pile work was in progress. Driving work induced vibrations in the adjoining structures. Work was immediately stopped. Piling system was modified and rotary large diameter piles were adopted. Finally the work was completed satisfactorily without any vibrations.

Precast driven piles

A group of three piles was to be driven. While driving, first pile went 13 M, second pile went 10 M and the third pile went 7 M. Testing was advised. Group test of piles was done as per IS codes. Test results were satisfactory.

Cast in situ piles

Cast-in-situ piling work was in progress. While placing pile cap reinforcement vibrations were felt. When pile was excavated, heavy under water current was found. The damaged pile was completed with steel liner. Load test was carried out and the pile was found to be safe.

Tilting piles

Cast-in-situ piling work was in progress. No soil investigation was done. During piling work, it was observed that piles started tilting causing shifting of piling rigs etc. Investigations revealed that, earlier there was a pond at the location of the site, which was filled up afterwards.

Probably piles were not properly socketed. This was a dangerous condition. It was advised to carry out a load test before construction.

Warping of precast pile

A project involved bored precast piles. Strata encountered was weak marshy land. 19.5 M long, dia 500 piles were proposed. It was observed that after casting, the piles warped slightly. Investigations revealed that, in casting yard, after 7 days, piles were shifted directly on reclaimed ground for curing. This resulted in settlement of the portion of the ground in contact with the piles. Hence the piles warped. Piles were subsequently supported on cross-wooden members for curing to prevent warping. Load test was also carried out and results were satisfactory.

Wrong selection of piling system

Piling work was in progress for an office building in a crowded commercial area. Bored precast type, 15 M long piles were contemplated. However, at the work site, adequate space was not available for casting and curing of piles. Eventually, piling system had to be modified to bored cast in situ piles. This delayed the completion of the project.

Improper structural analysis & design

Project involved group piles with common pile cap. Expert opinion was sought. Discussions revealed that proper analysis was not carried out. Computer software used was not reliable. Structural design was done without considering the following:

a. Eccentricity of system

b. Effect of lateral moments, axial thrust etc

c. Provisions in IS codes for design of pile caps

Proper structural analysis had to be carried out and the entire design had to be revised. Pile cap thickness was also modified by providing shear keys etc. with extra reinforcement.

Under ground water current

G + 2 hostel building was constructed on bored cast-in-situ piles. In each apartment of the building, 1.2 M wide balcony was provided for a room having a size of 3 M x 2.5 M. Soon

after the construction was over, the building started tilting gradually. Investigations revealed possibility of necking of pile & bulging of reinforcement. Building was declared unsafe. Under ground water current was suspected. This is a very critical factor and should be thoroughly investigated, especially near costal areas, old river / nallah.

Conclusion

Thus, in order to avoid such practical problems likely to be posed during construction of pile foundations, following points should be carefully considered:

- Detail soil investigation should be carried out.
- In case of readymix concrete, regular testing should be carried out for quality reasons.
- Piling work should be carried out through reputed and reliable agencies only.
- In major projects, initial pile test should be carried out on a sample
- Structural consultant should first visit the site before selecting a piling system.

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EARLY HIGH STRENGTH CONCRETE: ADVANTAGES & CHALLENGES

Shivram Bagade & Nagesh Puttaswamy

Abstract :

Fast track construction has become the order of the day. In many ways, technological advancement has been a boon for the mankind. But, at what cost? Speeding cars are thrill but the risks are also a part of the system. The concept of 'time saved is money saved' induced the fast track in construction industry. Since then, engineers and administrators are trying everything to make construction faster. Early High Strength Concrete (EHSC) is one of the approaches. The history of high strength concrete is about 35 years old. In the late 1960s invention of water reducing admixtures lead to high strength precast products and structural elements in beams were cast in situ using high strength concrete. Today, construction industry is facing some challenging demands for manufacturer of cement and admixtures to achieve:

- 40 MPa of M60 concrete in 3 days
- 50% of target strength in 24 hours
- 12 MPa in 10 hours

And the list is growing. While fulfilling these demands, we must ensure that the long-term durability of structures is not affected adversely.

Some observations made during the trials for EHSC shall be discussed here along with some of the durability issues. The rheological parameters in connection with the durability aspects need to be given a careful attention. The technology of EHSC is being used more in the infrastructural projects and pre-cast industry. In some cases it is being used indiscriminately and in a few cases it is being adopted without proper technical backup. Sometimes, cement and admixtures are selected/ rejected based on economic criteria and little thought is given to the sensitive issues of the cement admixture compatibility and formation of micro plastic-cracks. Further while using EHSC, we must ensure that this product does not get in to a trap like the use of fly-ash in concrete, which even today has not got 100% confidence with the technical fraternity.

Till about 1970s concrete that could achieve strength of above 40MPa was classified as high strength concrete. When concrete mixes of about 60MPa and above were commercially produced, the bench mark for the High Strength Concrete was raised. Since the development of superplasticising admixtures in the late sixties, the Japanese with their high strength pre-cast products using '*naphthalene sulfonate'* and the Germans with under water concrete using *'melanine sulfonate'* were the pioneers of the technology.

Three to four decades ago, despite the availability of concrete as versatile construction material, most of the high-rise buildings all over the world used steel elements as structural frame. The famous Twin Towers at Manhattan (World Trade Centre) had steel frames. The reason was that with the strength of concrete available in those days the members made of concrete would have been bulky and ugly.

With the advent of high strength concrete, the bulkiness in the concrete members is gone and we have been able to make slender section in concrete too. Since then high strength concrete has come a long way and is running a race to reach the strength of steel. The concrete of the order of 200 MPa has become a reality at least at the laboratory conditions and concrete of the order of M60 to M120 are commonly used at sites. The properties of the high strength concrete are well studied and understood by the engineers today. The use of high strength concrete no longer raises eyebrows.

How is high strength concrete achieved ?

The high strength in concrete can be achieved by using one of the following methods or a combination thereof:

- Higher cement content
- Reducing water cement ratio
- Better workability and hence better compaction

High strength requires a high content of cementitious material in the concrete mix; say above 400 kg per m^3. Higher content would lead to higher thermal and drying shrinkage, and there would be a stage when any further addition of cementitious material may not increase the strength. From the durability aspects, the minimum and maximum cement content in concrete is governed by the codal provisions. Reduction of water cement ratio has also its own limitations especially in the site conditions. Thus emerged the contribution of cementitious material for strength of concrete.

- Addition of pozzolanic admixture like the Pulverized Fly Ash (PFA) or glass granulated blast furnace slag (GGBS) which helps in formation of secondary C-S-H gel, thereby results in improvement of strength. The addition of pozzolanic admixture like the fly ash used as admixture will reduce the strength gain for the first 3 to 7days of concrete and will show gain beyond 7days and give a higher strength in the long term.
- Addition of mineral admixtures like the silica fumes or metakaolin or rice husk ash (RHA). They will start contributing in about 3 days. The RHA has an advantage over the PFA because the RHA is more reactive.
- Use of chemical admixtures like the Super-plasticizer or Hyper-Plasticizer, set controlling admixtures will help in attaining the higher strength in concrete. The research and the experience indicate that the admixtures based on the Poly Carboxylic Ethers (PCE) called the hyper plasticisers are the best suited for the job as they have a water reducing capacity of 18% to 40% with respect to the control or reference concrete.

- Combination of all of the above or some of the above to achieve the desired strength. The combination of at least a few of these methods has now become inevitable as the HSC came along with some complexities like higher shrinkage, higher heat of hydration etc., all these complexities needed to be neutralized or controlled. Most of the problems were handled by a combination of PFA or GGBS and PCE admixture.

In order to accelerate hydration of cement, steam curing methods are also adopted. However, this may not result in higher ultimate strength. The strength gain at early age can be achieved by replacing a part of the fine aggregate by fly ash or blast furnace slag, without increase in the water requirement of the concrete mixture.

Some of the codal requirement of the high strength concrete

Compressive strength	60 MPa or more	
Durability	Permeability < 5 mm	as per DIN 1048
Workability	to be placed in areas of high congestion	

Properties of the ingredients used in the HSC are as follows:

Properties of Cement:

Compressive strength	> 60 MPa
C3A Content	< 6
Fineness	300 ± 20 Sq. m per kg
Total alkali content	Max. 6% expressed as Na_2O
C_3S	> 50%
C_2S	>24%
C_4AF	>15%
LOI	< 2%

Properties of Fly Ash:

PFA is required for enhancing the strength, impermeability and durability of concrete.

For the said reasons Class F PFA has to be used.

It reduces segregation and bleeding in fresh concrete and creep in hardened concrete. It also lowers heat of hydration.

Chemical requirements:

SiO_2	> 60%
$SiO_2 + Al_2O_3 + Fe_2O_3$	= 85%
LOI	2% Maximum
Fineness	Max.10% (retained on 45 Micron)

Aggregates:

Fine Aggregates (Sand): Should fall in Zone II

Chemical Admixtures:

The HWRA has to be used, normally the PCE admixtures are formulated for the specific needs. High Range Water Reducing Admixture (HRWRA): It is a known fact that for durability of the structure, permeability in concrete plays a major role. One of the important factors that govern the issue of water/cement ratio during the manufacture of concrete is lower the water cement ratio lower will be the capillary pores and hence lower permeability and enhanced durability.

Poly Carboxylic ethers (PCE) based admixtures called hyper plasticizers invented in the 1990's have fulfilled the conditions in a significant manner. The advantages of which are being exploited in the production of High strength and High Performance Concrete. The water reducing capacity of these admixtures is between 18 – 40% of the control or reference concrete. These admixtures assist in achieving higher slumps more than 180 mm at much lesser w/c ratios (less than 0.30). They impart better control over the rheology of the concrete and that is one of the reasons such admixtures are always used for producing Self Compacting Concrete. The only disadvantage of these admixtures is that they do not have a longer retention beyond 45 minutes and are always used along with retarding agents, adding to the complexities of the mix. These complexities need to be handled very carefully. However, the construction chemical industry has come out with combination of chemicals or one can say cocktail of chemicals to meet the demand.

Requirements of Construction Industry:

With the construction industry using pre-cast elements and post-tensioning methods, the requirement of the high strength concrete has become inevitable and the engineers have to overcome these drawbacks which, to a great extent, they have been able to do. The construction of modern days has become fast track where the importance of investment in the formwork has led to the use of high strength concrete. The speed of construction and its technology is measured in terms of the number of cycles of the use of formwork.

A Few examples are as under:

CASE 1:

Infrastructure project

This concrete requirement was for precast segmental girders to be post tensioned for a fast track infrastructure project. The time is the main objective of the contract between the consumer and contractors. The segments needed to be hoisted into place within a record small time, and were to be post-tensioned. The continuity in work, the construction area being very congested for work, demanded that the infrastructure for the casting moves further at the earliest.

Grade of concrete required		M50
Special requirement specified		
01	Minimum strength required in 24 hrs	25 Mpa
02	Workability required : Initial collapse slump	
03	Workability required: Pumpable concrete after 90 minutes.	
04	To get high early strength without stickiness	

These large segmental girders for an elevated highway project

	Trial 1	Trial 2	Trial 2
Mix Grade	M-50	M-50	M-50
Cement OPC 53 grade	5.4	5.4	5.4
CA- I 20 mm	6.228	5.292	5.472
CA- II 12.5 mm	5.748	6.372	5.472
CA- III 6 mm	2.4	2.712	2.76
Crushed Sand	8.448	8.448	9.12
Total Water (including absorption)	1.974	1.98	1.99
Admixture	M- 715	M- 715	M- 715
Dosage (in %)	@ 0.6	@ 0.6	@ 0.7
Slump / Flow (in mm)			
0 min	210	200	200
30 min	150	150	165
Wet Density (kg/cum)	2462	2405	2482
Compressive Strength (N/sq mm)			
01 Day	28.04	30.04	31.32
02 Days	40.12	42.44	46.20
07 Days	47.80	48.20	50.00
Batch size / cum	0.012	0.012	0.012

CASE 2:

Infrastructure project

Grade of concrete required		M60
Special requirement specified		
01	Minimum strength required in 24 hrs	40 MPa
02	Workability required as in SCC	
03	Quantity of cementatious material Pre-fixed – fly ash from a fixed source	
04	Fine aggregates	100% crusher dust

The concrete had to achieve more than 50% of its final strength in 24 hours. The whole process had to take place in about 14 hours of the final setting time of cement.

The project requirement was for the shell - plate roof elements to cast on ground and needed to be hoisted to place and was post-tensioned. The requirement of early high strength of concrete was for the fact that the members needed to be de-shuttered early and moved to the curing yard and the number of cycles of formwork was critical economical criterion. The segments had special shapes and folds. Hence, there was a requirement of the self compacting property. The retention of workability and the requirement of early high strength were the contrarian requirements.

The concrete in this case was made at the captive batching plant at site and the necessary conditions were achieved with a couple of alternative cement brands. The concrete placed into the mould using transit mixers within the site had to retain the workability for nearly 45 min to 1 hour. The details of the mix design cannot be provided here as all trials were done by the consumer and permission to publish the same could not be obtained. The admixture used was especially fine tuned for the specific requirement and it had to undergo further fine tuning with respect to change in the ingredient sources. Several thousand cubic meters of concrete has been consumed. Is it going to be the trend setting bench mark for other projects ?

CASE 3 : For Segmental construction of towers.

Grade of concrete required		M60
Special requirement specified		
01	Minimum strength required in 12 hrs	12 MPa.
02	Quantity of cement	Pre-fixed
03	Quantity of cementatious material	Pre-fixed – fly ash from a fixed source
03	High reactive mineral admixtures like Silica Fume	Not permitted for economic reasons
04	The minimum strength requirement was modified to 12 MPa in 10 hrs.	

Initial slump: Collapse.

Slump after 30 min: Collapse and flow min 450 mm.

The requirement of this concrete was for the making of pre-fabricated segments of towers cast at logistically suitable place. The circular segments with variable diameter from one end to other have to be fabricated in a yard and hoisted to the curing yard. The cost of the formwork and the restriction on the space available for the casting area required the segments to be hoisted from the casting yard to the curing yard. The early strength requirement was to cater for the hoisting load. The consumer was applying a protective coating on the precast segments for ensuring the durability. The segments were transported in trucks to destinations as far as 600-700 kilometers for actual use. The economic criterion for the consumer required that there should be at-least 2 cycles of casting for every 30 hours.

The following mix design was arrived at for getting the desired conditions. An average of nearly 10 to 15 trials were made with different selected brands of cements. The critical results between different brands of cement are listed in the tables below.

Workability:

Time in minutes	Slump in mm	Flow in mm	Remarks
0	Collapse	575 to 625	These parameters were kept
30	Collapse	495 to 525	constant for all brands of
60	110	Nil	cement for a definite dosage
90	50	Nil	of admixture
120	20	Nil	

It was observed that the loss of slump and flow was rapid after the 45-50 minute mark. The values indicated here are the average of several tests that were conducted. After 60 minutes, the concrete exhibited unusual stiffness and elastic/spongy feel.

Mix proportioning details			
Mix grade	M60	M60	M60
Cement 53 grade OPC	**Brand X**	**Brand Y**	**Brand Z**
Cement	470	470	470
PFA	130	130	130
W/C	0.26	0.26	0.26
20 mm	454	454	454
12.5mm	454	454	454
Natural sand	750	750	750
Free water	154	154	154
Total water	-	-	-
Admixture	G-30(S3)	G-30(S3)	G-30(S3)
Dosage(%)			
Comp strength, MPa (average of all cube results)			
12 Hours	14.15	5.38*	4.5*
14 Hours	14.33	13.33*	12.85*

It may be noted that for the Brands Y and Z, the gain of strength between the 12th hour and the 14th hour were almost 3 times.

The Drawbacks of the Technology:

The implication of such rapid strength gain is alarming and needs a serious attention. Considering the fact that the final setting time of most brands of cement in India is around 120 minutes, there will be an issue of the durability of such concrete. Irrespective of these issues, technology has been able to satisfy the requirement of the customer and the work is in progress. As technologists we need to generalize the requirement for the use as many more requirements may come and all may have to have captive batching plants to produce these special concrete.

The high strength concrete has great advantage in the modern construction scenario as statistics shows that it has not only delivered in the strength aspects but also in terms of economy. Studies show that an approximate increase of 5 times in the strength of concrete will have only about 3 to 3.25 folds increase in concrete. If the designer is able to exploit the conditions, the over all costing of the project will defiantly come down. Hence lots of projects today are adopting the high strength concrete of the order of M60 or above regularly.

The advancement of the formwork technology is making the erecting and removing of formwork system easier and simpler. The cycle times for formwork are reducing drastically as one week one slab concept are widely being adopted. In the developed countries, this cycle period is about 4 days. In order to achieve this, the concrete has to attain a certain specified minimum strength in that time.

That means Early High Strength Concrete will become the order of the day.

The precast concrete element manufacturers are already adopting the technology even without proper technical know how. When we have been able to incorporate the self compacting property or the self leveling property with a slight modification of cost, the consumer should be able to make the concrete element with a slightly lower cost. Now, if the consumer can increase the production of the elements in terms of more number of cycles per formwork, the project cost will come down.

Type of concrete	Cost	Number of cycles per month	Increase in cost	Increase in no. of cycle
Conventional	2900	30	-	-
Self compacting	3100	36	6.70%	20.00%
SCC/EHSC	3200	45	10.35%	50.00%

With all the parameters kept constant, this is a very attractive offer for any business proposition. The construction industry would be turning towards this technology called the EHSC in near future.

The technologists should deliberate and frame proper guidelines on this concept/technology or else this concept could be put to use indiscriminately. The deliberations are more important now, because this technology is being used in several infrastructure projects.

Conclusions:

EHSC is here to stay but we need to be careful that we do not forget more important aspect of durability of concrete. There are few products that are available to ensure durability in these concrete as coatings and secondary admixtures within the concrete mixture. A careful effort should be made to impart knowledge on the protective system along with the technology of early high strength concrete. With many of the construction sites and some of the precast units being manned by non-technical or untrained personnel, the technology should be allowed to have sustained growth and not die down prematurely bowing to incubation problems.

The article depicts the views of the authors based on the studies and observations made by them while working specific cases and observations made there off. The inference of the information given in this article is left to the readers, it is only an effort made by the authors to open deliberations on the topic rather than conclude any thing.

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CHALLENGES IN HIGH RISE CONSTRUCTION

A. D. Makhare

Introduction:

Availability of land is becoming a major constraint for horizontal building construction in metros and cities. Land prices are also increasing day by day. With increased density of population new generation is now opting for space at upper floors. All these factors are leading to growth in High Rise Buildings, towers & sky scrapper construction. Speed, quality, safety and economy are the essence of any construction work. It is Important to note that with conventional working methodology and untrained workers, it is a challenge for developers, builders & contractors to complete the project with due importance to above four factors. Real difficulties start for construction of building above 7 floors. This article describes the operations and advantages of some working equipments, which are very useful in construction projects.

Current Challenges:

1. Speed:

Speed of construction mainly reduces because of the following factors:

- Travel time required to transport manpower and raw material to upper floors
- Inadequate space for storage of material.
- Risk of accidents
- Transportation of delicate items like, sanitary ware / glass fitting and other valuable materials

2. Quality:

In order to control quality of construction, frequent visits are required to be made by the site supervisors/ project engineers and various consultants. For this purpose, at higher floors, it is important to have:

- Easy means of manpower transport
- Sufficient and safe working space to get comfort level to worker and mason.
- Mechanized material handling system

3. Safety:

It has been observed that the 80% of accidents at construction sites are due to workers falling from working space or fall of material. Survey reveals that every 65 worker among 1000 workers meet with accidents at site. Following are the areas carrying more risk of accidents:

- Working with steel/ bamboo scaffolding for external work like brickwork, plaster, painting etc
- Travel of man and material through staircase under construction.
- Working on wooden platform for painting and sanitary fittings

4. Economy:

Labour rate of construction increases with stages of construction, however it can be minimized by installing appropriate equipments for various applications. Minimum wastage of material and effective use of manpower economizes the project cost.

Solutions to Challenges:

To overcome the challenges in High Rise Building Construction it is necessary to increase degree of mechanization. Effective use of equipments gives returns on investment in a reasonable period and handles most of the challenging working conditions at various stages of construction. All the developed countries have higher mechanization for construction for High Rise buildings with following equipments:

1) Passenger cum Material Handling Lift
2) Suspended (Hanging) Platform
3) Mast Climbing (Works) Platform
4) Concrete Pump
5) Tower Crane
6) Tower Hoist

Nowadays, use of tower crane, concrete pump and tower hoists are observed at many sites in India. However, awareness about application of Passenger cum Material lift (PM Lift), Works Platform and Hanging Platform has not yet reached the desired level. Brief application of these equipment is described below:

1) Passenger Cum Material Lift:

This lift differs from common passenger Lift. It works on rack and pinion technology and does not require any guide rails for continuous support. Variable frequency drive avoids jerks during starting and stoppage of lift. It is installed at outer face of wall

as well as inside duct and anchored to wall in interval of 3 to 6 meter. It comes in 1 & 1.5 ton capacity and travel with speed of 30 meters per minute. It has 3 safety brakes, which don't allow lift to fall. The lift can be erected up to a height of 150 M. It requires minimum foundation and is very easy to shift. It is also very easy to operate.

Applications:

- Safe and fast transportation of delicate material like glass fittings, sanitary ware etc
- Transportation of workers at different floors for different stages of work
- Transportation of site engineers and supervisors, architects, structural engineers, quality inspectors etc
- Lift is very effective in case of extension of upper floors in preoccupied buildings

2) Works Platform:

It is also called mast climbing Works Platform. It also works on rack and pinion technology powered by 2 nos 10 HP gear motors. Platform of different length and width travels up and down on column mast. Platform can be extended close to wall through telescopic arrangement provided. Platform requires level ground to rest on and requires no heavy foundation. It is shifted from one place to another by means of self driving unit. Platform can be erected to a height of 100 meters. It comes with magnetic and mechanical brakes to stand against free fall. Working with Works Platform is safe and fast. It is the best substitute to conventional bamboo and steel scaffolding. Because of its unique applications most of the developers and builders have started installing such platforms at their sites.

Applications:

- Brickworks of external wall
- Plastering work
- Plumbing and Electrical work
- Aluminium and Glass cladding
- Cleaning of Aluminium and glass cladding up to self standing height
- To carry reinforcement steel and other construction material
- Special painting and lettering work

3) Hanging Platform:

This is also called as Suspended Platform. Such platforms are suspended from terrace of building through wire rope. Platform width can be made available as per requirement. It may suspend from height of 100 meter or more than that. Platform comes in modular form hence can be carried anywhere easily. It neither requires any foundation nor anchoring thus avoids disturbance to original structures. It is very smooth in operation and is operated through remote provided in platform. It comes with 2 fail-safe brakes. Working with these platforms increases confidence level of workers and Project Engineers too. Working with Hanging Platform increases output of work by more than 30% with reduction in 30 – 40% labour cost.

Applications:

- Plastering of straight vertical eternal walls
- Aluminium and glass cladding
- Cleaning and maintenance work of aluminium and glass facade
- External plumbing fitting, electric fitting, minor repair work.
- External work of building where ground access is not possible
- Transport of man and material at required heights
- Painting work

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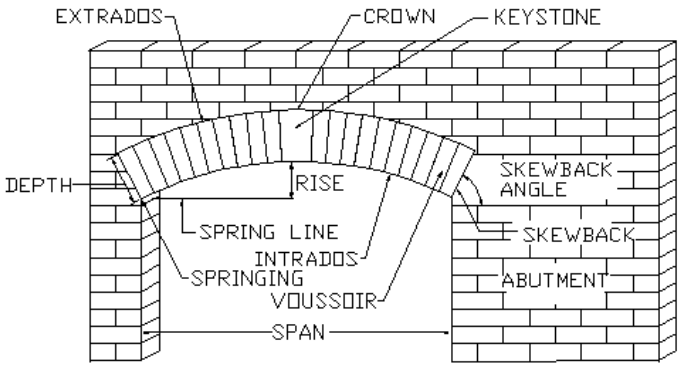
DESIGN OF CONCRETE ARCHES FOR BUILDINGS

T. Rangarajan

Introduction :

Since the olden days, arches have been used in houses, mansions and bridges. At that time neither concrete nor reinforcement was invented. The principle used was that the shape of an arch is an invert of bending moment diagram wherein there is no tension in the member. So by inverting the BM diagram the structural engineer can either design an arch or a roof truss where the member will have no tension but only compressive forces. The shape of the member can be a circle, parabola, catenary or an ellipse. In the olden days many masonry structures were constructed using the shapes mentioned.

As there is no single exhaustive book covering detailed design of Reinforced Concrete Arches, the author presents a compilation of his studies and work on arches.



Terms:

Extrados: The curve, which bounds the upper edge of the arch

Intrados: The curve, which bounds the lower edge of the arch

Crown: Apex of the arch's extrados. In symmetrical arches, the crown is at the midspan

Rise: Maximum height of the arch soffit above the level of its spring line

Soffit: Surface of an arch or vault at the intrados

Span: Horizontal clear dimension between abutments

Spandrel: Masonry contained between a horizontal line drawn through the crown and a vertical line drawn through the upper most point of the skewback

Springing: The point where the skewback intersects the intrados

Springer: The first voussoir from a skewback

Spring Line: A horizontal line, which intersects the springing

Voussoir: One masonry unit of an arch

The Arch Action:

The main characteristic of arches is the presence of horizontal thrust induced by the unyielding supports, which prevents the curved beams from straightening under vertical loads. It acts towards the arch and produces compressive stresses at all sections of the arch. The horizontal thrust also produces negative bending moments (BMs) at all sections of the arch, which counteract the positive BMs due to the loads. Thus the second characteristic of arch action is that in addition to the BMs each section is subjected to a direct thrust and also that at all sections the static BMs due to load is considerably reduced by the BM due to horizontal thrust. These characteristics are common to fixed as well as hinged arches.

Design of RCC arch (IS 4090-1967):

Load on arch:

IS 4090-1967, clause 5.2.1.2 says that "when the ratio of fill above the crown to span of the arch less than 1, full weight of fill will be borne by arch. This means that when the arch is used at lintel level the weight of the brick masonry above the lintel and below the floor is carried by the arch. This can be calculated and applied over the span.

Rise of arch:

The rise of the arch should generally be between 1/3 to 1/4 of the span for economy; the smaller value being applicable to relatively larger span and large value for relatively smaller spans.

Reinforcement:

Main bars:

The cross-sectional area of longitudinal reinforcement should not be less than 0.8% of the area of arch section. The practice of placing bars only on the tension face and bending them to other face where the BM changes sign is not recommended. This is due to the fact that the arch is subjected to compressive forces only.

Transverse reinforcement:

In arch slabs the transverse reinforcement shall be provided for distribution temperature and shrinkage. Min area shall be 0.2% of sectional area.

The above clauses of IS code offer a fair idea of the arches. Concrete arches may be built either with plain or reinforced concrete. But referring to the book "Concrete Plain and Reinforced Vol-II" by Frederic and Thompson it is important to note that plain concrete arches should never be used unless

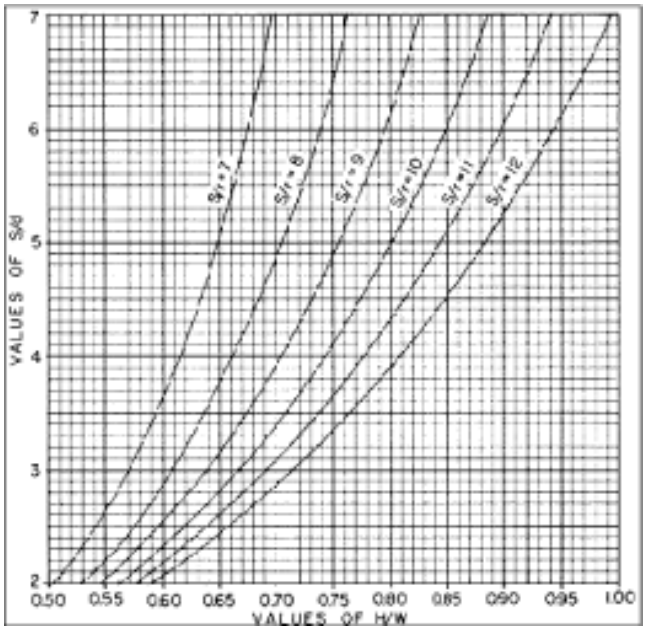
they rest directly on rock foundation. Reinforcement is particularly necessary for flat arches because there the effect of rib shortening and change of temperature is especially large.

The area of tensile reinforcement must not be less than 0.25% of the largest gross cross section of the arch.

Placing of reinforcement:
Referring "Concrete Plain and Reinforced Vol-II" by Frederic and Thompson, the main reinforcement runs longitudinal with the arch. Since for different conditions, tension can occur near the intrados as well as the extrados, reinforcement is usually placed near both faces of the arch. In addition to the longitudinal bars, cross bars are used which tie the main bars and also prevent any longitudian craks. To prevent buckling of longitudinal bars hoops are used around the top and bottom bars. The amount of longitudinal reinforcement usually 0.5% to 1.0% of the cross section of arch.

To take care of tensile stresses, which may develop at top at the crown and at the bottom at the springing, usually the reinforcement is placed symmetrically about the arch axis, one half of the total area being used near each face. Instead of rectangular stirrups, if it is spiral it increases the allowable compressive strength of the concrete.

Minor and major arches :
(Ref: BIA Tech. Notes 31A)
Depending upon the span of the arches they are classified as minor and major arches.
Minor arches are those whose spans do not exceed 6 ft and with maximum rise to span ratios of 0.15.
Major arches are those with spans in excess of 6 ft or rise to span ratios greater than 0.15



THRUST COEFFICIENTS FOR SEGMENTAL ARCHES

The above graph is the representation of thrust coefficients (H/W) for segmental arches subjected to uniform load over the entire span. Once the thrust coefficient is determined for a particular arch, the horizontal thrust (H) may be determined as the product of the thrust coefficient and total load (W). To determine the proper thrust coefficient, one must first determine the characteristics of the arch, S/r and S/d where S is the clear span, r is the rise of the soffit and d is the depth of the arch.

In these ratios and in the ratios and equations that follow, all terms of length must be expressed in the consistent units.

Minor arch loadings:
The loads falling upon a minor arch may consists of live loads and dead loads from floors, roofs, walls and other structural elements. These are applied as point loads or as uniform loads fully or partially distributed.

The dead load of a wall above an arch may be assumed to be the weight of wall contained within a triangle immediately above the opening. The sides of this triangle are at the angle of 45 degrees to the base. Therefore, its height is half of the span. Such triangular loading may be assumed to be equivalent to a uniformly distributed load of 1/3 times the triangular load.

Superimposed uniform loads above this triangle may be carried out by arching action of the masonry wall itself. Uniform live and dead loads occurring below the apex of the triangle are applied directly upon the arch for design purposes. Heavy concentrated loads should not be allowed directly on minor arches. This is specially true of jack arches. Minor concentrated loads resting directly on the arch may safely be assumed to be equivalent to a uniformly distributed load of twice the concentrated load.

Major arch loadings:
The principal forces acting upon arches in buildings are the result of vertical dead and live loads and wind loads. It is often assumed that the entire weight of masonry, above the soffit, presses vertically upon the arch. This certainly is not correct, since even with dry masonry a part of the wall will be self-supporting. The designer must rely on empirical formulae, based on the performance of existing structures, to determine the loads on an arch. The dead load of masonry wall supported by an integral arch depends upon the arch rise and span and the wall height above the arch. It may be considered to be either uniform (rectangular) or variable (complementary parabolic) in distribution or a combination thereof.

In the reference "Frames and Arches" by Valerian Leontovich, solutions are given for arches with rise-to-span ratios (f/L) ranging from 0.0 to 0.6. The following assumptions for loading of such arches are believed to be safe:

For a low-rise arch, f/L=0.2 or less, a uniform load may be assumed. This load will be weight of wall above crown of the arch up to a maximum height of L/4 where f is the rise and L is the span of the arch. For higher rise arches a dead load consisting of uniform plus complementary parabolic loading may be assumed. The maximum ordinate of the parabolic loading will be equal to a weight of wall whose height is the rise of the arch. The minimum ordinate of the parabolic loading will be zero. The uniform loading will be weight of the wall above crown of the arch up to a maximum height of L^2/100.

Uniform floor and roof loads are applied as a uniform load on the arch. Small concentrated loads may be treated as uniform loads of twice the magnitude. Large concentrated loads may be treated as point loads on the arch.

Applicable formulae & equations :

The general equation for the Parabolic arch is

$y = 4f(1-x/L)x/L$

Fixed arches:

For **vertical UDL**,

M and Q are zero at any section of the arch. V= W/2

H1= H2= WL (K-2JT)/ Ff

When X ≤ L/2, Nc= H1cosØ+ W/2 (1-2X/L) sinØ

For **Vertical complementary Parabolic loading** for a parabolic arch,

M1= M2= WL(JS-2T)/ F

H1= H2= WL(K-2JT)/ Ff

V1= V2= W/2

J = 1+ (ä/ γ); F = è- γJ; K = S è/γ; è =2(á + â)

When x <= L / 2:

$$M_x = M_1 + WL/16\,[1-\{(L-2x)/L\}^4] - H_1 y$$

$$Nx = \frac{W}{2}\left(\frac{L-2x}{L}\right)^3 \sin\phi + H1\cos\phi$$

$$Nx = \frac{W}{2}\left(\frac{L-2x}{L}\right)^3 \sin\phi + H1\cos\phi$$

$$Qx = \frac{W}{2}\left(\frac{L-2x}{L}\right)^3 \cos\phi - H1\sin\phi$$

Notation. In these equations, the subscripts 1 and 2 denote the left and right supports respectively. The subscript x denotes values at any horizontal distance, x, from the origin. f is the angle, at any point, whose tangent is the slope of the arch axis at that point. (See Table 4.)

M = moment
N = axial force
Q = shearing force
f = rise of the arch
W = total load under consideration
H = horizontal thrust
V = vertical reaction

L = span of the arch

S and T are load constants (see Table 5).

Steps:

1. Establish principal dimensions of the arch.
2. Depending upon the established shape and f/L ratio of the arch, obtain the corresponding K value of the arch (Table 3).
3. Obtain the elastic parameters (α, β, , δ) from Table 6. Perform the algebraic operations with the given equation as given above.

TABLE 3
Values of k

Arch rise-to span-ratio f/L	0.2	0.3	0.4	0.5	0.6
Arch k value	1.28	1.56	1.9	2.4	2.8

TABLE 4
Values of ϕ

Arch Ratio f/L	Values of ϕ whe			
	0 and L	0.1 L and 0.9 L	0.2 L and 0.8 L	0.3
0.2	38° 40'	32° 37'	25° 38'	
0.3	50° 12'	43° 50'	35° 45'	
0.4	58° 00'	52° 00'	43° 50'	
0.5	63° 26'	58° 00'	50° 12'	
0.6	67° 23'	62° 29'	55° 13'	

TABLE 6
Arch Parameters α, β, γ and δ

Arch k Value	α	β	γ	δ	eme olic enti
3	7.2	2.8	8.229	2.971	
2	5.6	2.4	7.314	2.286	6095
1.8	5.28	2.32	7.131	2.149	4429
1.6	4.96	2.24	6.949	2.011	5333
1.4	4.64	2.16	6.766	1.874	3714
1.2	4.32	2.08	6.583	1.737	
1.4	S	0.8437			0.4876
	T	0.5400			0.3286
1.3	S	0.8343			0.4800
	T	0.5300			0.3214
1.2	S	0.8229			0.4724
	T	0.5200			0.3143

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PRODUCT REVIEW

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CORROSION OF REINFORCEMENT

Rupali Joshi and Umesh Dhargalkar

Preamble:

Reinforced cement concrete is the most commonly used construction material. One of the major problems faced by the construction industry today is the corrosion of reinforcement. A long coastline, tropical weather & a long monsoon season of our country accelerate corrosion in steel. Based on a study conducted in USA, corrosion is said to attribute about 55% of distress in structures. The present article discusses various aspects of corrosion from a structural engineer's point of view.

What is corrosion?

A few metals such as gold occur naturally, whereas engineering metals like steel are derived from their ores by smelting. During smelting metal absorbs energy required to free it from its ore. This is an unstable state & the metal tends to get rid of this extra energy to revert to its more stable & natural state as an ore. *This reversion process is known as corrosion.*

Electrochemical Process

Corrosion is basically an electrochemical process, which requires an anode, a cathode, an electrolyte & an electrical circuit. Various reactions involved in this process are as follows:

Iron, being unstable, looses electrons & acts as an anode

$$Fe \rightarrow Fe^{2+} + 2e^-$$

At cathode, O_2 in presence of H_2O, reduces to hydroxide ions

$$O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$$

OH^- ions react with ferrous ions to precipitate iron hydroxide

$$Fe^{2+} + 2OH^- \rightarrow Fe(OH)_2$$

Rust is then quickly formed by the oxidation of the precipitate

$$4Fe(OH)_2 + O_2 \rightarrow 2Fe_2O_3 \cdot H_2O + 2H_2O$$

Corrosion cells

A combination of anodic & cathodic areas is called corrosion cell. They are formed due to non-uniform penetration of corrosive material, heterogeneous properties of concrete, cracks, patch/ partial repair etc. Depending upon the cell size (i.e. how apart the cathode & anode are), there are 2 forms of cells; macro & micro cells.

- Micro cells: Concrete being heterogeneous, penetration of corrosive materials is not uniform along the length of the steel bars. As a result anodes & cathodes are set up on the individual bars resulting in formation of a micro cell.
- Macro cells: Distribution of corrosive materials is not uniform throughout the concrete section. As a result, bars on one face are exposed to higher concentration of corrosive material & act as anode, while the bars less exposed to corrosive material act as cathode resulting in formation of a macro cell.

Corrosion of steel is due to a combination of micro & macro cells.

Concrete as an environment

Presence of abundant amount of calcium hydroxide gives concrete a very high alkalinity (pH of 12 to 13). High alkalinity provides a protective film of iron oxide on the surface of the steel. In the initial stages of corrosion, ferrous hydroxide is formed, which in presence of oxygen & water oxidizes to iron oxide to form the passivation film. Thus the protective film itself is a result of initial corrosion of steel bar. As the film is being formed, oxygen diffusion rate is reduced, which in turn, reduces the corrosion rate. As long as the film is not disturbed, the steel remains passive & protected from corrosion.

Types of corrosion

- Uniform: e.g. atmospheric corrosion of exposed steel
- Pitting: A localized form of corrosion by which cavities or holes are produced in the material. It is initiated by localized damage to protective film.
- Stress: Cracking induced from the combined effect of tensile stress & a corrosive environment. Fine cracks are developed, which cannot be detected easily. However, a disastrous failure may occur unexpectedly.
- Galvanic or bi-metal: When 2 dissimilar metals come in an electrical contact in presence of an electrolyte, the less noble metal undergoes corrosion.
- Crevice: A crevice is a narrow gap between a piece of metal & another piece of metal e.g. gap between 2 plates bolted together, gap between welded components etc.

Factors Causing Corrosion

- **Permeability of concrete**
  This is a major factor affecting corrosion. Adequate cement content & low w/c ratio should be ensured.
- **Inadequate cover**
  Leads to ingress of air, moisture, CO2 & chloride. RCC works should at least have minimum covers as specified in IS 456
- **Presence of cracks**
  Certain amount of cracking always occurs in tension zone of RC members depending upon the amount of tensile stress in steel. Maximum permissible crack width as recommended in IS codes should be strictly observed.
- **Carbonation**
  Calcium Hydroxide is present in concrete. It reacts with CO2, forming CaCo3, resulting in shrinkage cracks. This is Carbonation. It lowers alkalinity of concrete & reduces its effectiveness as a protective medium. In dense concrete, carbonation is confined to surface layers & depth may not exceed 20 mm in 50 years.
- **Presence of chlorides**
  Chlorides can enter during mixing as an admixture or as a contaminant in the constituents or from an external source. They break down the protective oxide layer. In fresh concrete about 7500 to 8000 ppm Cl ions start corrosion. However, when alkalinity reduces, the Cl level needed to start corrosion is lowered to below 100 ppm.

- **Presence of Sulphates**
  Sulphates/ sulphides do not cause corrosion on their own. In high concentration they attack concrete itself. Their presence in the electrolyte makes it more acidic and more conductive.
- **Presence of moisture**
  In presence of moisture, concrete acts as an electrolyte and encourages corrosion. In a hot and humid country like India, it is essential that concrete should be less permeable.
- **Impurities in water**
  Impurities such as sulphates & chlorides when present in mixing or curing water, lead to early & rapid corrosion. Limits as provided by the IS code for sulphates & chlorides should be observed.
- **Alkali-Silica reaction (ASR)**
  Silicaceous minerals in some aggregates react with water in an alkaline environment to form silica gel, a material used to absorb moisture. As silica gel swells when it absorbs moisture, and causes concrete to crack, and white, weeping deposits of silica appear. In many cases, ASR is superficial & harmless, but it is unattractive and difficult to treat. Use of alkali reactive aggregates should be avoided. Most effective remedy is to dry out the structure.
- **Electrolysis**
  Passage of direct electric current through concrete or reinforcement can cause rapid and serious corrosion. This may happen if there is electrical leakage of direct current & electrical system is not effectively grounded.

Corrosion Testing

- **Half cell potential**
  The simplest way to assess the severity of corrosion is to measure the corrosion potential since it is qualitatively associated with the steel corrosion rate. To measure half cell potentials, an electrical connection is made to the steel reinforcement in part of the member you wish to assess. This is connected to a high impedance digital millivoltmeter. The other connection to the millivoltmeter is taken to a copper/copper sulfate or silver/silver chloride half cell, which has a porous connection at one end which can be touched to the concrete surface. This will then register the corrosion potential of the steel reinforcement nearest to the point of contact. By measuring results on a regular grid and plotting results as an equipotential contour map, areas of corroding steel may readily be seen. Half-cell potential measurement only reveals the corrosion probability at a given location and time. Long-term monitoring of the half-cell potential reading is more meaningful. Evaluation of rebar corrosion from the "absolute" half-cell potential values may mislead engineers and cause errors in judgment if other factors are not taken into account.

- **Carbonation Depth**
  Carbonation ingress can be tested by breaking a piece of concrete surface & spraying it with phenolphthalein. This gives a pink colouration in normal concrete & is colourless in carbonated region so that depth of carbonation can be readily observed.
- **Chloride content**
  One type of test consists of collecting & powdering the samples, obtaining water extracts & conducting titration for determining water soluble chloride content. This gives chloride content in the cover region. Rapid Chloride test Kit: This consists of obtaining powdered sample by drilling, collecting the samples from different depths, mixing with a special chloride extraction liquid & measuring electrical potential of the liquid by chloride-ion sensitive electrode. This method is rapid & gives acid soluble chloride content.
- **pH meter**
  pH is determined by collecting broken samples/ core samples. Water extracts are analyzed in lab using pH meter.
  pH value > 12.5 … Sound concrete
  pH value < 9 … Corrosion prone concrete
- **Resistivity mapping**
  Corrosion of reinforcement depends on algebraic summation of electrical currents originating from the corroding sites on the steel & flowing through the moist surrounding concrete to non-corroding sites. Hence the electrical resistance of concrete plays an important role in determining the magnitude of corrosion at a given location. It is expressed in terms of "Resistivity" in ohm-cm. The values vary quite significantly over a structure. For a general monitoring, a resistivity check is important because long term corrosion can be anticipated in structures where resistivity vales are below 10,000 ohm cm. If the values fall below 5,000 ohm-cm, corrosion must be anticipated at a much earlier period (within 5 yrs) in the life of a structure.
- **Other methods** commonly used for in field assessment of corrosion include visual inspection, delamination survey, concrete resistance measurement, concrete cover-depth survey, carbonation profile determination, and rate of corrosion measurement at selected locations.

Corrosion Protection

3 variables influence corrosion process, material, design & environmental variables.

- Material variables include cement type, admixtures, aggregate type & gradation, water cement ratio.
- Design variables include depth of cover, properties of concrete, size & spacing of rebars, max crack widths etc
- Environmental variables include source of chloride ions, temperature extremes, wet-dry cycles, relative humidity & to some extent applied live loading

Although little can be done to control environmental variables, material & design variables can be adjusted to build durable structures that can resist corrosion. Corrosion protection strategies can be grouped into 2 categories, concrete & reinforcement

- **Concrete**
  In preventing corrosion, the most critical property of concrete is permeability, which determines the extent & rate of corrosive materials. Concrete must be dense, with a good bond between aggregate & cement paste. Proper compaction & curing is essential for low permeability
- **Fiber Reinforced Concrete (FRC)**
  Thousands of small fibers are distributed randomly in concrete during mixing. Fibers increase toughness & tensile strength & improve the cracking deformation characteristics of concrete. Ultimate strength of concrete can be increased as much as 5 times by adding fiber reinforcing. Materials used in fiber reinforcing include acrylic, asbestos, cotton, glass, nylon, polyester, polyethylene, rayon, rockwool and steel.
- **Blended cement**
  Replacing at least 50% of OPC with pozzolanic materials (e.g. silica fumes, fly ash, blast furnace slag) decreases the permeability of concrete & favourably interferes with the chemical reaction during hydration & in the corrosion reaction. These materials are about 100 times finer than cement & hence they give a filler effect & reduce permeability. Their use results in less cement paste & hence less shrinkage & less cracking. Even government is in favour of blended cements because disposal of waste products like fly ash & blast furnace slag has become a public issue.
- **Corrosion inhibitors**
  These are chemical admixtures added to concrete during batching. They delay the onset of corrosion. Also available as surface applied liquids & slurries.
  àThis results in long-term durability of structures. It extends the time before initiation & reduces the rate of corrosion in propagation period. Inhibitors are organic, inorganic or mixed. They can protect by affecting anodic reaction (active) or cathodic reaction (passive) or both. An active type of inhibitor forms an oxide film on the surface of steel. Passive type of inhibitors protect by reducing the rate of Cl ion migration. Nitrate & nitrite of calcium are commonly used inhibitors, which are inorganic in nature. Nitrates are more easily available & economical & hence their usage is more common.
- **Corrosion Resistant Steel (CRS)**
  These are low alloy steels having good corrosion resistance. CRS offers an improvement factor of 1.5 to 1.6. The bars are produced using corrosion resistant elements & special thermo-mechanical treatment (TMT). Microstructure resulting from TMT leads to higher corrosion resistance as compared to CTD bars. Particularly suitable for coastal region. Alloying elements include Cu, Cr, Ni, P etc. Cu reacts with saline water to form an insoluble layer over steel. It also plugs pores in protective film and retards corrosion. P acts as an inhibitor & slows down corrosion. Cr helps in formation of spinel oxide layer, which is a poor conductor of electrons thereby reducing corrosion rate.
- **Microcomposite steel**
  A low carbon steel with about 8% chromium & has a very high corrosion resistance due to its microstructure. Basic problem of steel is that it contains microscopic fingers of 2 different components, ferrite & carbide, that act like a tiny battery when electrolyte is present. Corrosion is due to the micro electric currents produced by these micro-galvanic cells. Chemical composition & production process results in a virtually carbide free steel. In the absence of continuous paths of carbides, micro galvanic cells are minimized & corrosion is controlled. It also has a higher strength (700 MPa). It costs same as epoxy coated bars but is easier to handle.
- **Fiber Reinforced Polymers**
  Composite materials made of fibers embedded in a polymeric resin are used as an alternative to reinforcement. Carbon fiber reinforced polymer (CFRP), and glass fiber reinforced polymer (GFRP) rods are available.
  Benefits:
  - Impervious to chloride ion and chemical attack
  - Tensile strength greater than steel
  - 1/4th weight of steel reinforcement
  - Electrically and thermally non-conductive

  Disadvantages
  - They are expensive.
  - Field bends are not allowed, and not-weldable.

  Suitable for marine structures, parking structures, bridge decks, highway under extreme environments, and structures highly susceptible to corrosion.

- **Reinforcement coatings**
  Coatings are cheaper than & hence are more popular. But a disadvantage is that they may be physically damaged or electrochemically penetrated so that the base steel is again vulnerable to corrosion.
- **Cement slurry coating**
  It is coated over the rebar to provide a strong bond between rebar & concrete thereby reducing possibility of trapped air in the gap & hence the localized corrosion. Carried out in India in the name of CECRI coating. It cracks during application & needs careful handling.
- **Polymer coating**
  Polymer coatings are applied over steel to avoid penetration of corrosive materials in concrete. Only applicable for dry atmosphere. Performance is poor in polluted & moist atmosphere.
- **Galvanized bars**
  Bars having hot-dipped zinc coating applied by dipping the properly prepared steel bar into a molten zinc bath. Should be used in non-polluted atmosphere. In polluted atmosphere, Cl ions can easily affect the galvanized steel & lead to corrosion. Zinc corrodes when exposed to chloride ions. Corrosion product of zinc occupies a smaller volume than iron, causing little or no disruption to the concrete mass. Care should be exercised to eliminate any electrical contact between the galvanized steel & other metals.
- Epoxy coated bars (or fusion bonded)
  Epoxy coatings are solid dry powders, electro statically

sprayed over cleaned & pre-heated rebars. It is a barrier system intended to prevent moisture & chlorides from reaching the steel. It electrically insulates the steel to minimize the flow of corrosion current. If epoxy bars are to be used, they should be used for all reinforcing in a component. This technique is becoming more popular because of high coating quality & low chances of failure.

Protection measures pertaining to steel can be arranged in the order of increasing cost as galvanizing, epoxy coating, stainless steel (clad/ solid) & impressed current cathodic protection.

Corrosion Control

Factors influencing the corrosion of reinforcement are:

- Amount of chloride ions at steel level
- Resistivity of concrete
- Temperature
- Relative humidity (Internal & external)
- Concrete microstructure

By controlling these factors to an acceptable level, corrosion of steel & the resulting deterioration of concrete can be minimized. Corrosion control systems are classified as mechanical systems & electrochemical systems.

- **Mechanical systems** are physical barriers that prevent or delay the ingress of harmful agents through concrete. These include admixtures, sealers, membranes, overlays & coatings on steel bars. Coatings used are either organic (fusion bonded epoxy coatings) or metallic (nickel, stainless steel, zinc). Nickel & stainless steel protect by being a barrier system and more noble i.e. have lower potential than iron to corrode. Zinc coating protects by being sacrificial or more active i.e. have greater potential than iron to corrode. Corrosion resistant materials include stainless steel & fiber reinforced polymer rebars (FRP)

- **Electrochemical systems** include cathodic protection, desalination, realkalization. These are used as rehabilitation measures and not for new construction.
  - **Cathodic protection**
    The electrochemical nature of corrosion process provides a basis for cathodic protection. There are 2 basic types of cathodic protection viz. Impressed current & Sacrificial anode (Galvanic). Bars of metals (zinc, aluminium) less noble than the metal to be protected are used as sacrificial anodes. Electrons flow from the sacrificial anodic metal into the metal to be protected, thereby making it the cathode of the corrosion cell. To protect a large structure, however, many anodes will be required.
  - **Desalination (Chloride ion removal)**
    Negatively charged chloride ions are pulled towards positively charged anode mesh and are pulled out of the concrete.
  - **Realkalization**
    An electrolyte, which is an alkaline solution is drawn into the concrete to raise its pH.

These are the modern methods to stop corrosion by restoring the passive environment.

Conclusions

- With poor concreting, corrosion of ordinary rebars leads to spalling after 5 yrs, investing in CRS would stretch it further by another 3 yrs, however, better concreting practices can extend the service life beyond 50 yrs.
- Patch repair is generally used to rectify localized corrosion damage. However, if compatibility between the repaired & un-repaired areas is not ensured, such repair system leads to new corrosion attack due to macro cell formation between the repaired & un-repaired areas.
- Use of stainless steel can be a cost effective approach to reduce the frequency of repair & extend the service life of RCC structures.
- Always remember the magic formula
  Focus on to the concrete that covers the steel; ensure uniform cover of compact concrete with a low w/c ratio & build long lasting structures!

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In the past few months, ISSE journals and other correspondence sent to some of our members have been coming back undelivered. It appears that they have moved to a new address. A list of such members is given below. We are very keen in having their latest contact details with us so that we can reach them in future.

***I**f you know any of these members, please ask them to get in touch with us (Phones: 022-24365240, 24221015) or send an email to isse@vsnl.net or update their contact details through our website www.isse.org.in.*

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