INSDAG YEARBOOK 2020-2021

INSTITUTE FOR STEEL DEVELOPMENT AND GROWTH (INSDAG)

793, Anandapur, Ispat Pragati Bhawan
KOLKATA – 700 107
E-mail: ins.steel@gmail.com, Website: www.steel-insdag.org

<table>
<tr>
<td>INSDAG</td>
<td>
Steel is the backbone of all industries and the basic ingredient for growth and development of a country. Traditionally, the fortunes of the steel industry have been linked to the economic cycle of the country. Per capita consumption of steel speaks volumes about the relative position of the country on the development frontier. In India the per capita consumption of steel stands low compared to developed and developing countries. Moreover, steel is completely recyclable and environment friendly. Hence, a large potential exists in furthering the usage of steel in various segments of industry. Institute of Steel Development and Growth (INSDAG), a non-profit making, member based organization established by Ministry of Steel and the major steel producers of the country. The Institute primarily works towards the development of advanced design methodologies & technical marketing by expanding applications of steel in different segments of industry, upgrading skills & know-how, creating awareness amongst potential users and communicating the benefits of steel. Our founding members are SAIL, Tata Steel Ltd., RINL, JSW Steel Ltd., and Arcelor Mittal Nippon Steel India Limited (AM / NS) apart from Ministry of Steel. INSDAG has got very good networking among the member organisations/professionals for exchange of ideas. The Institute is registered as a "Society" under Societies Registration Act of West Bengal.
Director General looks after the daily affairs of the Institute and Executive Council provides guidance and direction. Two other functional committees namely the Working Group and Project Review Committee provide administrative and technical guidance respectively. The Institute has defined its mission, role, and functions and has evolved its short, medium and long term Activity Plans. The Institute primarily works towards the development of technology in steel usage and the market for the steel fraternity. Some of its roles are:

Creating awareness amongst potential users on affordability of steel.
Bringing out technical publication on steel applications.
Providing technical advisory services on materials, construction practices etc.
Upgrading the skills of work force by refresher courses / training programmers.
Communicating the benefits of steel through life cycle cost studies.
Providing requisite thrust to increase steel consumption in rural areas.
Assisting in the development of ancillary industries for creating new market.

</td>
</tr>
</table>

INSDAG Year Book

2020-2021

Pydi Lakshmana Rao M.Tech (Str) IIT KGP

General Manager (Civil & Structural)

Institute for Steel Development And Growth
"Ispat Pragati Bhawan",793, Anandapur, Kolkata - 700 107
E-mail: ins.steel@gmail.com
Web Site: www.steel-insdag.org

Mission Statement

To work in unison for all the stakeholders in the steel industry so as to evolve ways and means for more efficient usage of steel and provide optimum value to the customer

Publication Number INS/ PUB/155
January 2023

Price Rs.   /-

PREFACE

The primary drivers of steel consumption in the country would be massive infrastructure as well as the progress of a number of steel intensive structures like machinery & equipment, consumer durables and automobiles.

INSDAG Yearbook 2020 - 2021 contains the technical articles from experts in steel industry. The document contains article like Economy is Hallmark of Parallel Flange Sections – A Boon to the Indian Steel Construction Industry by Mr. Pydi Lakshmana Rao, Steel Concrete Composite Columns by Mr. Arijit Guha , Corrosion in Industrial Steel Structures and Mitigation by Mr. Pratip Bhattacharya; Mr. Manos Kumar De , High Strength Structural Steels by Mr. Asim Kumar Samanta , Efficient Construction with Steel Weld Mesh Fabric by Dr Jayanta Kumar Saha, Innovative Usage of Steel Hollow Sections in Steel-based Construction by Mr. Ravi Kumar, A Journey into the World of Corrosion by Ms. Sohini Mitra , Transitioning to High Strength Steel for Structural Applications by Mr. Tamilselvan; Mr. Sahil Aggarwal; Dr PC Ashwin Kumar .

We believe that the range and scope covered by the technical papers in the yearbook covering the high strength steels, new steel materials like welded wire mesh, parallel flange sections, composite construction, corrosion protection of steel structures and innovative use of steel hollow sections will definitely create interest in steel fraternity and increased use of steel intensive structures.

INSDAG Year Book
2020-2021

---------------------------CONTENTS--------------------------

ECONOMY IS THE HALLMARK OF PARALLEL FLANGE SECTIONS - A BOON TO INDIAN STEEL CONSTRUCTION INDUSTRY

Pydi Lakshmana Rao

General Manager (C&S)
Institute for Steel Development & Growth

INTRDUCTION

A structural engineer's responsibility is to design the structural members of buildings, bridges, dams, offshore platforms etc, with maximum efficiency and minimum cost satisfying the strength and stiffness requirements. Selecting the suitable structural arrangement, design methodology and choosing the right structural sections of required strength can accomplish the economy.

Indian standard medium sections are available in one size only for each beam depth. However, in case of parallel flange beams (in view of the Universal Rolling Technology), more number of beams having the same beam depth but with varying flange and web thickness, flange widths and weight per unit length (Fig. 1) will be available giving more flexibility to the designers & economy to the owner.

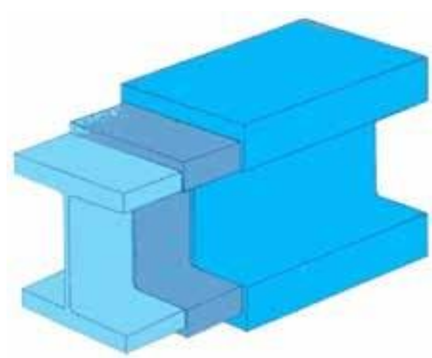


Fig.1: Various Shapes with Equal Chamber Size

With the setting up of a major Rail & Universal Beam Rolling Mill at their Raigarh works in Chhattisgarh, JSPL (Jindal Steel & Power Limited) is the first Company in the Indian market to produce much-awaited tailor made hot rolled parallel flange beams and columns of wide range upto 900 mm depth. These beams and columns are well accepted by consultants, designers and fabricators because of their substantial cost benefit over conventionally available tapered beams or built up sections.

Steel Authority of India Limited (SAIL) is producing NPB, WPB sections confirming to IS: 808-2021 (Formerly IS: 12778) and HE sections confirming to DIN 1025. These sections are available from NPB 100x55x8.1 to NPB 750x270x202.5, WPB 160x160x23.8 to WPB 450x300x171.12 from their Universal rolling mills at ISP, Burnpur and DSP, Durgapur.

These sections are available in different grades as per IS 2062-2011 and also able to produce copper bearing structural's to increase corrosion resistance. These grades are rolled as per customer's specifications.

Parallel Flange Sections from SAIL are also available in the following foreign specifications such as ASTM-A-36, JIS-G-3101-SS400, BS-4360 (Grades 40A, 43A, 43B, M 43C, 50B, 50C), EN-10025 (Grades S-275 JO, JR, S-335 JO, JR), DIN-17100 (Grades ST 37.2/44.2) as mentioned in their website (www.sail.co.in).

Parallel flange sections produced by SAIL and JSPL are available in different grades with yield strength of 250 to 450 MPa. These sections can be welded easily. Parallel flange I-Sections to be used as beams of nominal size ranges from 180x90 mm to 900x300 mm and column sections from 150x150 mm to 400x400 mm are being produced and are made available in domestic market by JSPL leading to significant economy in steel construction.

With the availability of large number of beams with different statical properties having the same beam depth besides having the advantage of parallel flange over taper flange will give the designers, architects and construction agencies great flexibility in choosing the right sections depending on applications. Also these sections have better sectional properties (section modulus, radius of gyration) compared to conventional I - Beams which are produced now in India. The load carrying capacity of parallel flange sections is higher under direct compression compared to that of similar I-Sections available today. Also connections to the flanges are simpler since no tapered washers etc. are required.

In view of above it is highly recommended to have the efficient parallel flange sections in construction industry to bring down the overall cost of the structures. Almost all the countries (Germany, Japan, USA etc.) use these efficient parallel flange sections and have their own national standards for the same.

The present IS: 808-2021 dealing with parallel flange section covers sections upto 900 mm beam depth. This Indian Standard incorporates a wide of range sections with proper grouping upto 900 mm depth.

MAJOR ADVANTAGES OF PARALLEL FLANGE BEAMS

- Possibility of broad range of statical properties having the same depth of beams permitting selection of the most optimum flange width and thickness and web thickness

Much better sectional properties such as section modulus and radius of gyration. Parallel flange beams exhibit much higher load carrying capacity under direct compression

Parallel flange I sections used as beams offer substantial savings in cost

Connections to the flanges are simpler since no washers are required (Fig. 2)

Butt Welding of plates at the edge of flanges is easier

Fig.2: Easy Connections Using Parallel Flange Sections

AVAILABILITY

Parallel flange beams are available in three categories

1. Narrow flange beams (NPB)
2. Wide flange beams (WPB)
3. Bearing pile sections (PBP)

Narrow and wide flange beams can be supplied in any of the three sub-categories

1. Light weight
2. Standard weight
3. Heavy weight

MATERIAL GRADES

These sections can be supplied in material grades conforming to IS: 2062-2011. Grades E 250, E 300, E 350, E 400, E 450 are manufactured by JSPL.

SECTIONAL SPECIFICATIONS

Parallel Flange Sections shall be made as per British, German, American or any other international specifications in addition to the Indian specification.

At present parallel flange sections are available from SAIL upto a maximum depth of 900 mm and width 300 mm with varying flange and web thickness which are available from their state-of the art Universal Rolling Mill. Sections will confirm to the tolerance limits of IS: 1852 and they can also be produced to any other international standard.

APPLICATION OF PARALLEL FLANGE SECTIONS

Parallel flange sections are invariably used in developed countries in almost all civil engineering structures like bridges, railway stations, car parks, buildings, stadiums, shopping complexes etc., due to their excellent statical properties and flexibility in choosing right section. Connections are simpler in case of parallel flange sections. This will helps to reduce the overall structure cost. Parallel Flange Sections particularly UC sections are suitable for columns. Large column free spans are possible using parallel flange sections with high grade steel. Number of columns can be reduced by 50% in Multi level Car Parks as per the study report (INS/PUB/019) prepared by INSDAG.

SAVINGS IN MATERIAL AND MONEY

Parallel flange sections and bearing pile sections can be used as beams and columns in steel structures, without going for fabricated or compound sections. Rolled section is always preferable to avoid extra fabrication cost.

The weight of steel beam / column required will be less in case of parallel flange sections compared to conventional ISMB sections. The advantages of parallel flange sections with respect to ISMB sections are shown in Fig. 3 , Fig. 4 , Fig. 5, Fig.6, Fig.7 and Fig.8.

Fig.3 shows that the saving in material by using PFS in comparison to ISMB.

Fig.4 shows that saving in material under compression Load. For example, to carry 500 kN by a member, use of either NPB 200x165x35.7 @ 35.7 kg/m or UC 152X152 @ 37 kg/m is enough compared to ISMB 400 @ 61.5 Kg/m.

Fig.6 shows that the range of bending capacity of parallel flange sections is much higher than that of ISMB.

Fig.7 shows that bending capacity of a parallel flange beam is always higher than that of ISMB for almost equal weight.

This is evident from the graphs indicating the axial compression capacities of parallel flange sections are higher compared to ISMB sections of similar weight.

Similarly the sectional weight of parallel flange sections is lower compared to ISMB sections for carrying same axial compression loads. Another big advantage is that these parallel flange sections are now available in different grades conforming to IS: 2062 - 2011 which will definitely reduce the steel structure cost considerably.

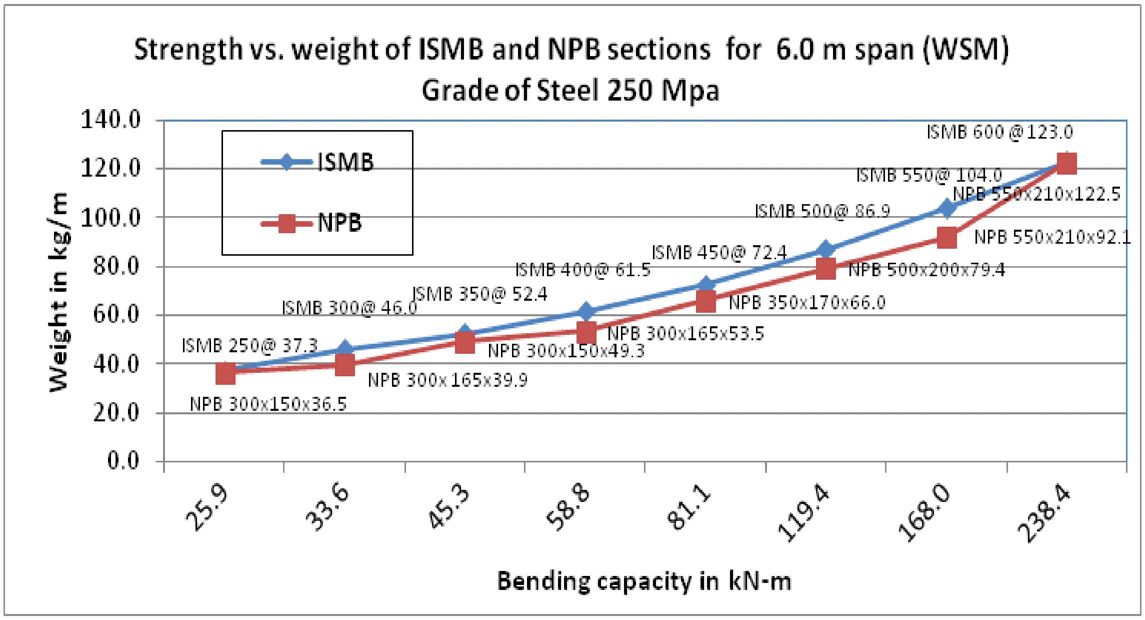


Fig.3: Weight of Steel Beam for Different Bending Moment Values

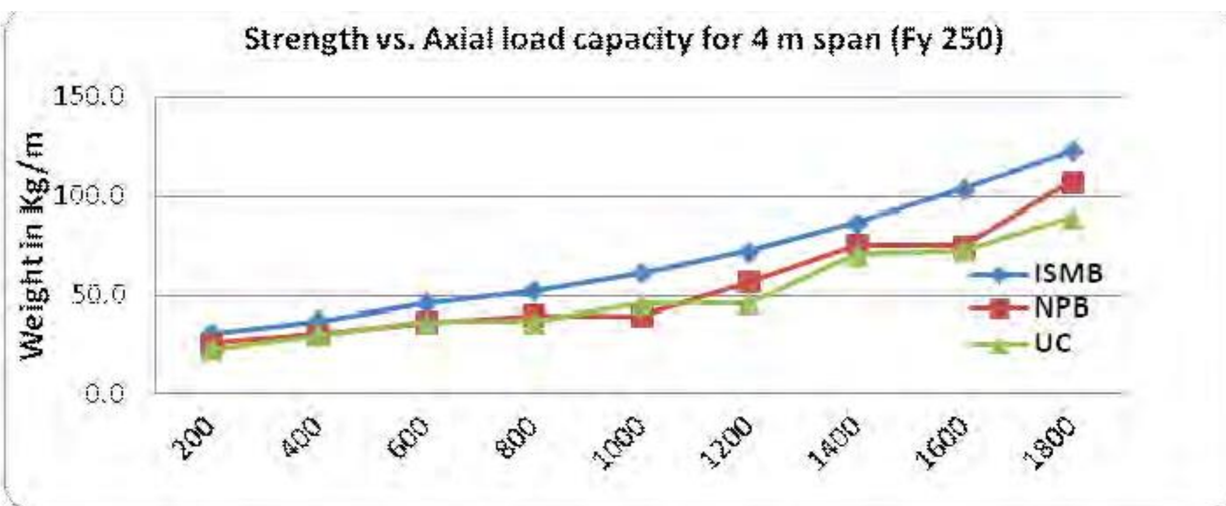


Fig.4: Weight of Steel Column for Different Axial Loads

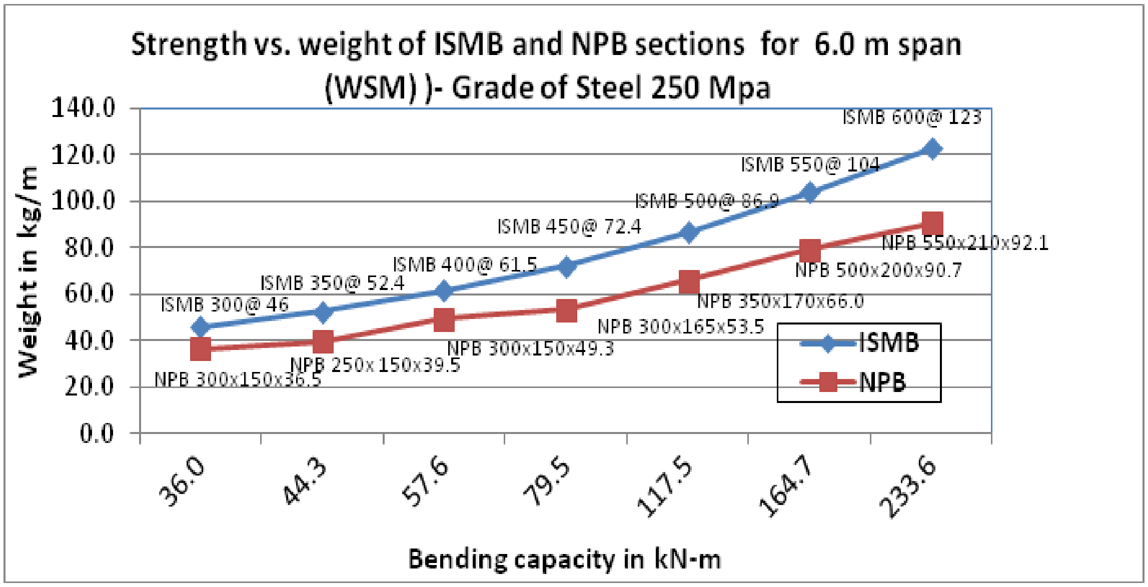


Fig 5: Strength vs. Weight of ISMB and NPB Sections

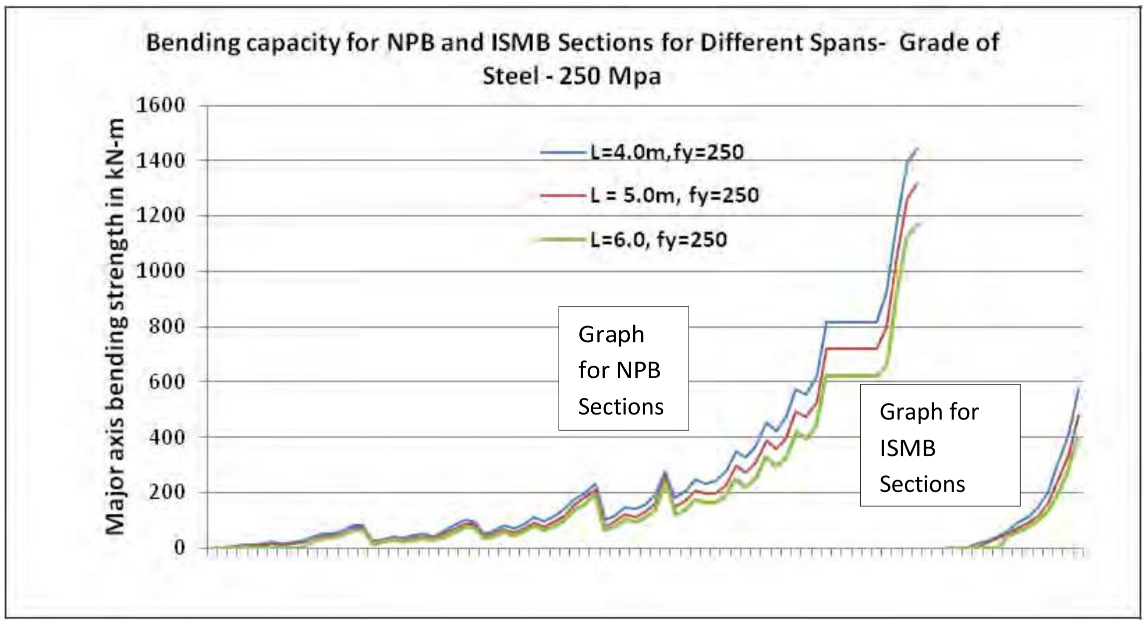


Fig. 6: Bending Capacity for NPB and ISMB Sections for Different Spans

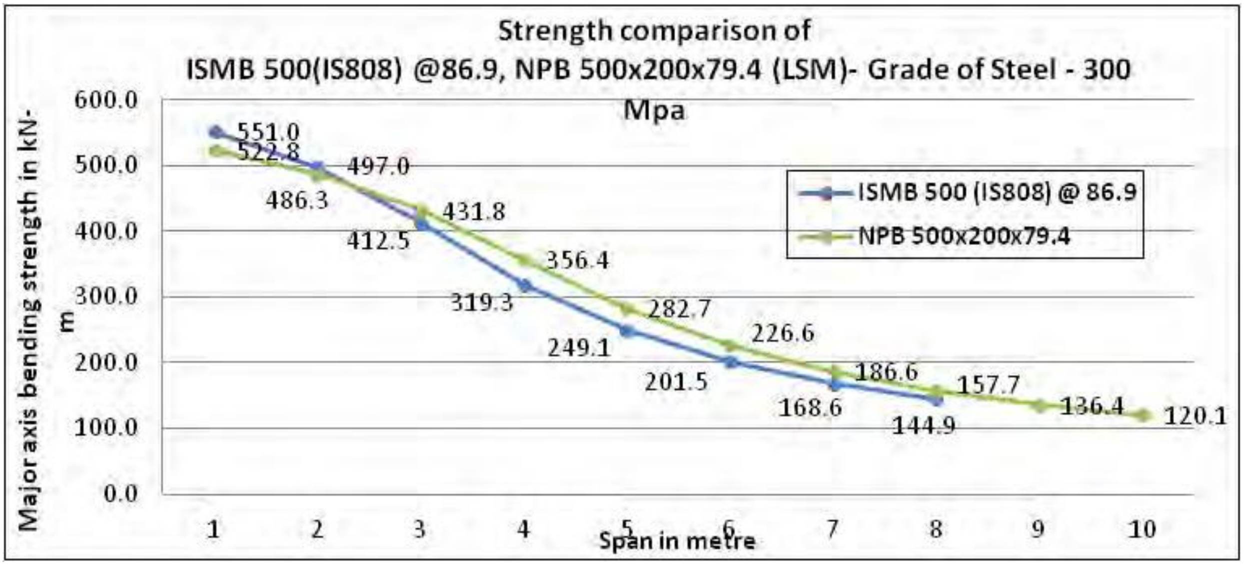


Fig. 7: Strength Comparison of ISMB 500, NPB 500x200x79.4 (LSM)

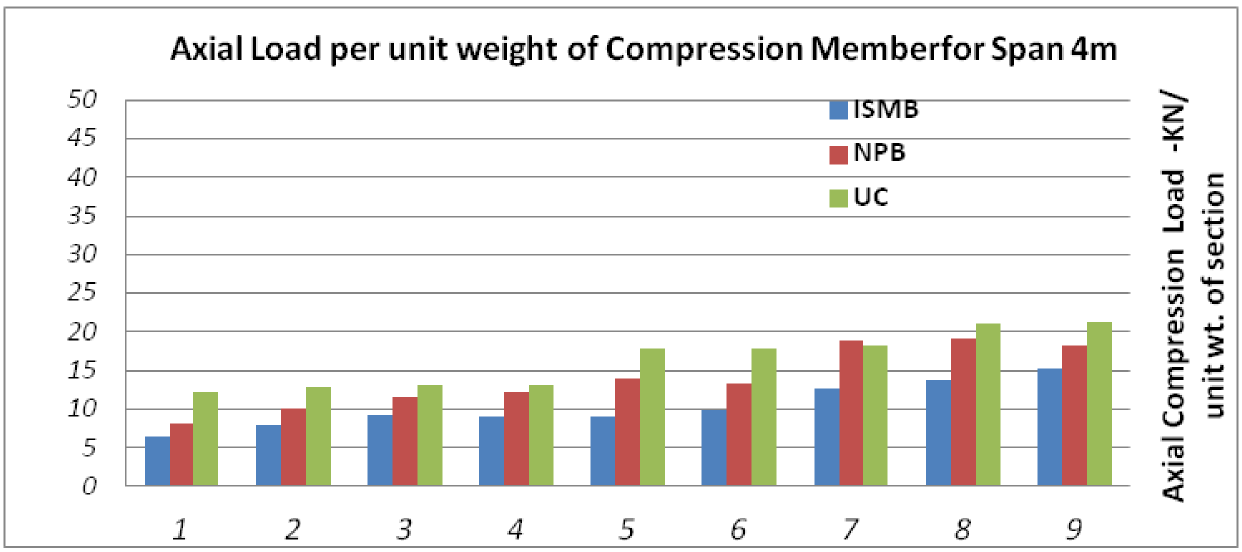


Fig 8: Axial Load per Unit Weight of Compression Member for Span 4m

Fig. 9: Car Park with PF Sections

The use of parallel flange sections is very useful where column-free long span are required. Multi-level Car Parks (Fig.9) is one such structure where more column free area is required for easy manoeuvring of vehicles.

CONCLUSIONS

Efficient parallel flange sections up to 900 mm depth are now available from Steel Authority of India and Jindal Steel & Power, JSPL.

The use of parallel flange sections reduces the use of 3-plated sections thereby reducing the fabrication work and increase the speed of construction.

Facilitates the long column free structures

Weight saving will be around 10-25% in case of bending members & 20-40% in case of axial compression member . The use of Parallel Flange Sections results in overall saving in material and cost of steel structures.

The savings are much higher if high strength parallel flange sections are used.

REFERENCES

1. . IS: 808 – 2021 , "Hot Rolled Steel Beam Column Channel and Angle Sections - Dimensions and Properties", Bureau of Indian Standards, New Delhi.
2. . IS: 12778 – 2004 , "Hot Rolled Parallel Flange Steel Sections for Beams, Columns and Bearing Piles - Dimensions and Section Properties", Bureau of Indian Standards, New Delhi.
3. . IS: 12779 – 1989 , "Rolling and Cutting Tolerances for Hot Rolled Parallel Flange Beam and Column Sections", Bureau of Indian Standards, New Delhi.
4. IS: 2062 - 2011 , "Hot Rolled Medium and High Tensile Structural Steel – Specification", Bureau of Indian Standards, New Delhi.
5. . "Design Manual for Effective Use of Parallel Flange Sections" Draft Version, Institute for Steel Development & Growth, Kolkata, 2022.
6. . "https://sail.co.in/en/products/sail-structural-sections", Website of Steel Authority of India Limited 2022.
7. . "https://www.jindalsteelpower.com/parallel-flange-beams-columns.html", Website of Jindal Steel & Power Limited, 2022.

STEEL-CONCRETE COMPOSITE COLUMNS

Arijit Guha
General Manager (Civil & Structural)
Institute for Steel Development and Growth

ABSTRACT

Some of the steel-based construction in the country so far has seen composite construction where the beams have been designed as composite with the slab supported by it on top. The earlier relevant code IS: 11384 – 1985 gave the Limit States Design for these beams. No stipulations or theory or guidelines were available to design composite elements like Columns. Also, the code did not cover composite slab. Hence, wherever required, most of the structures and its composite elements were designed with the help of foreign codes, mostly British or Eurocodes

The present draft code for composite construction IS: 11384 - 2022, gives guidance for design of all types of composite elements in structure, be it slab, beam or column. This article is aimed at giving a very brief outline and guidance about the utility of composite columns, its types and basic design procedure.

INTRODUCTION

Steel-concrete composite construction is an advanced technology which combines the compressive strength of Concrete with the tensile strength of steel to evolve an effective and economic structural system. Over the years this specialized field of construction has become more and more popular in the western world and has developed into a multifaceted design and construction technique. Steel-concrete composite construction over the last few years is getting highly popularized in the Indian scenario, but is still limited to commercial structures like multiplexes, some industrial structures, a few multi-storied constructions and road bridges. In this construction, structural steel work is typically used together with concrete; for example, steel beams with concrete floor slabs to attain composite action. This applies to buildings, road bridges, where concrete decks are normally preferred. Steel and concrete have almost the same thermal expansion apart from an ideal combination of strengths. Hence, these essentially different materials are completely compatible and complementary to each other.

Most of the steel-concrete composite construction till date has seen the use of composite beam along with steel columns and RCC slab. These is due to the fact that the earlier relevant design code IS: 11384 - 1985 dealt with only the design of composite beams. No stipulations or theory or guidelines were available to design composite elements like columns which carry axial loads as well as bi-axial bending moments. Also, the code did not cover composite slab wherein a thin concrete slab with minimum reinforcements acts together with the supporting steel profiled sheet, with or without embossments. The steel sheet acts as shuttering and provides for tensile strength of the slab against bending moment. The present revised code IS: 11384 – 2022, gives guidance for design of all types of composite elements in structure, be it slab or beam or column.

COMPOSITE COLUMNS AND TYPE

Columns are elements which carry all the loads from slabs, beams, etc., and transfer them to the foundation, and are thus the most vital elements in a structure. The present code has laid down detailed principles and guidelines to design composite columns which will enable a designer to utilize the strength of both the materials in the most judicious way to make the most rational design of a steel-based structure.

A steel-concrete composite column is a compression member, comprising either a concrete encased hot-rolled / plated steel section or a concrete filled tubular section of hot- rolled / plated steel and is generally used as a load-bearing member in a composite framed structure. Typical cross-sections of composite columns with fully and partially concrete encased steel sections are illustrated in Fig. 1. Fig. 2 shows three typical cross-sections of concrete filled tubular sections. It may be noted, that there is no requirement to provide additional reinforcing steel for composite concrete filled tubular sections, except for requirements of fire resistance where appropriate.

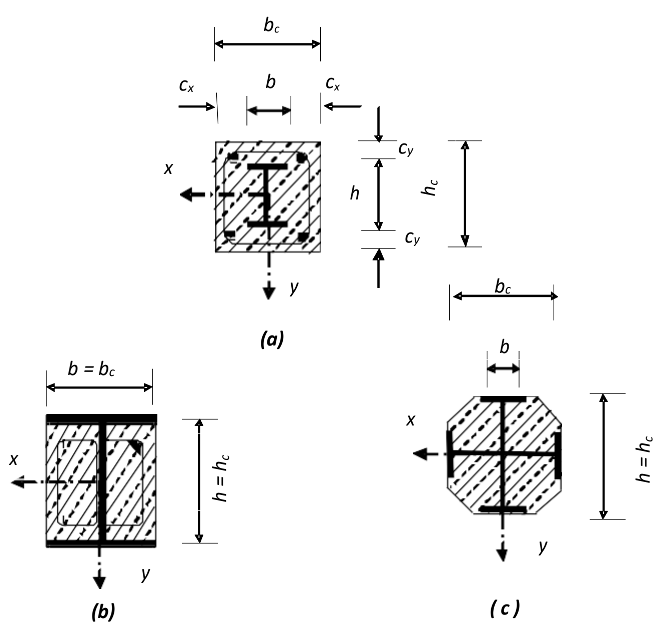


Fig.1: Typical Cross - Sections of Fully and Partially Concrete Encased Columns

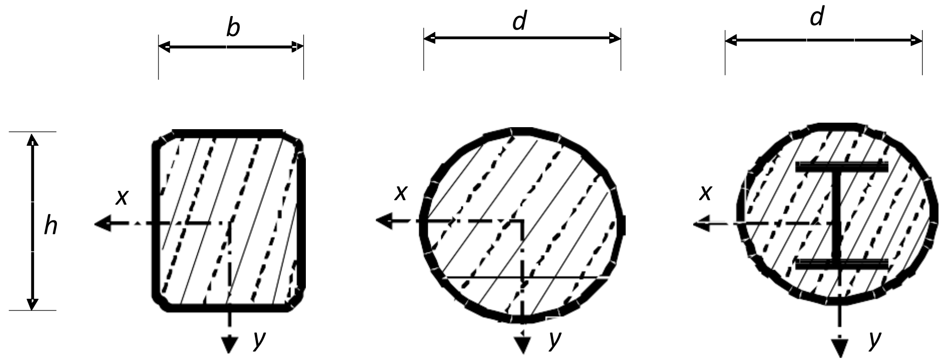


Fig.2: Typical Cross-Sections of Concrete Filled Tubular Sections

The initial development of composite columns was based on the need for providing effective fire protection for steel in buildings. It was common to encase the steel section within concrete. The weak concretes provided, resulted in very less enhancement in the overall strength of the section. Increase in strength and stiffness due to concrete encasement was ignored in the past, although increase in buckling resistance of the overall column was recognized. By the early part of the 1960's decade, studies showed that concrete encasement increases the load resistance of the steel columns. In addition to it, substantial economy in construction costs could be achieved by using better quality of concrete and ensuring composite action with steel by mutual interaction through chemical bond and friction or by using mechanical shear connectors in certain circumstances.

Provision of supplementary reinforcement in the concrete encasement prevents excessive spalling of concrete both under normal load and fire conditions. Concrete encased steel composite columns have become preferred structural form for earthquake resistant structures across the world.

ADVANTAGES

For a column in composite construction, initially the bare steel sections support all the construction loads, including the weight of structure during construction. Concrete is later cast around the steel section, or filled inside the tubular sections. The lighter weight and higher strength of steel permit the use of smaller and lighter foundations. The subsequent addition of concrete to complete the composite column element enables the building frame to easily limit the sway and lateral deflections. With the use of composite columns along with composite decking and composite beams it is possible to erect high rise structures in an extremely efficient manner and in a much faster pace requiring lesser time than conventional RCC or non-composite steel structures.

The advantages of composite columns are:

- Higher strength for a given cross sectional dimension.
- Higher stiffness, leading to reduced slenderness and higher buckling resistance.
- Good fire resistance in the case of concrete encased columns. However, for concrete filled tubes active or passive fire resistance measures need to be taken just like for pure steel columns
- Better protection to corrosion in encased columns.
- Significant economic advantages over either pure structural steel or reinforced concrete alternatives, more so for concrete filled steel tubes.
- Identical cross sections with different load and moment resistances can be produced by varying steel thickness, the concrete strength and reinforcement. This allows the outer dimensions of a column to be held constant over a number of floors in a building, thus simplifying the construction and architectural detailing.
- Erection of high rise building in an extremely efficient manner.
- Formwork is not required for concrete filled tubular sections.

DESIGN OF COMPOSITE COLUMNS

Like all structural elements, a composite column must also be designed for the Ultimate Limit State. For structural adequacy, the internal forces and moments resulting from the most unfavorable load combination should not exceed the design resistance of the composite cross-sections. While local buckling of the steel sections may be eliminated due to bonding with surrounding concrete, the reduction in the compression resistance of the composite column due to overall buckling should definitely be considered together with the effects of residual stresses and initial imperfections. Moreover, the second order effects in slender columns as well as the effect of creep and shrinkage of concrete under long term loading must be considered, if they are significant. The reduction in flexural stiffness due to cracking of the concrete in the tension area should also be considered.

At present, for design of composite columns, or for that matter any composite element, the relevant BIS code, IS: 11384 - 2022, may be referred for general steel construction. However, the relevant codes for steel bridges, IRC: 22 – 2015, may also be followed for all composite columns, till the new BIS code comes out. The method of design suggested in these codes, incorporates the latest research on composite construction. Isolated symmetric columns having uniform cross sections in braced/ non-sway and moment resisting frames may be designed by the simplified design method described in these codes. This method also adopts the European buckling curves for steel columns as the basis of column design. The simplified method is formulated for prismatic composite columns with doubly symmetrical cross-sections. The calculations of various design parameters are covered and the checks for structural adequacy of a composite column under applied loads are mentioned these codes. The ultimate safety of the column component is achieved by attaining the following boundary conditions as per the two codes mentioned above.

$$P \le P_d \qquad \text{(i)}$$

$$\frac{M_x}{\mu_{dx} M_{dx}} + \frac{M_y}{\mu_{dy} M_{dy}} \le 1 \qquad \text{(ii)}$$

$$\frac{M_x}{\mu_{dx} M_{dx}} \le \alpha_{mx} \qquad \text{(iii)}$$

$$\frac{M_y}{\mu_{dy} M_{dy}} \le \alpha_{my} \qquad \text{(iv)}$$

where,

P = Factored Applied Axial Load

P_d = Permissible Axial Force considering lateral Buckling.

M = Factored Design Moment in the two orthogonal axes of the column

M_d = Design Bending Resistance of the section about the bending axis, evaluated as in section

μ_{dx} *and* μ_{dy} = Moment resistance reduction factors in x and y directions, respectively

α_{mx} and α_{my} = reduction coefficient based on steel yield strength in x and y directions;

= 0.9 for $f_y \le 400$ MPa

= 0.8 for $f_y > 400$ MPa

FIRE RESISTANCE

Due to the thermal mass of concrete, composite columns always possess a higher fire resistance than corresponding steel columns. Composite columns are usually designed in the normal or 'cool' state and then checked under fire conditions. Additional reinforcement is sometimes required to achieve the target fire resistance. Some general rules on the structural performance of composite columns in fire are summarised as follows:

The fire resistance of composite columns with fully concrete encased steel sections may be treated in the same way as reinforced concrete columns. The steel is insulated by an appropriate concrete cover and light reinforcement is also required in order to maintain the integrity of the concrete cover. In such cases, two-hour fire resistance can usually be achieved with the minimum concrete cover of 40 mm.

For composite columns with partially concrete encased steel sections, the structural performance of the columns is very different in fire, as the flanges of the steel sections are exposed and less concrete acts as a 'heat shield'. In general, a fire resistance of up to one hour can be achieved if the strength of concrete is neglected in normal design. Additional reinforcement is often required to achieve more than one-hour fire resistance.

For concrete filled tubular sections subjected to fire, the steel sections are exposed to direct heating while the concrete core behaves as 'heat sink'. In general, sufficient redistribution of stress occurs between the hot steel sections and the relatively cool concrete core, so that a fire resistance of one hour can usually be achieved.

For longer periods of fire resistance, additional reinforcement may be provided. Steel fiberreinforcement is also effective in improving the fire resistance of a concrete filled column. It is also a practice in India to wrap the column with ferrocement to increase the fire rating. With the advent of Fire-Resistant Steel, the issue of fire resistance has become more easily solved up to 600^{0} C.

CONCLUSION

Steel is very strong material, especially in tension. Its higher strength to weight ratio puts this material in a superior position compared to other materials of construction. However, on account of many discouraging factors such as corrosion and lack of resistance in compression etc. does not allow it to be obvious choice of users.

Concrete is very strong in compression (though it has no tensile strength) and easy availability in small quantity makes it popular construction material. It lack of tensile strength is compensated by giving steel reinforcement within the concrete members of structure.

Developed countries have taken advantages of both the materials by adopting the concept of composite construction technology for structure. They have developed the standards for it long back. EN 1994 (popularly known as Eurocode 4: Design of composite steel and concrete structures) is one such international code developed in Europe more than 40 years back.

REFERENCES

1. Johnson R. P., "Composite Structures of Steel and Concrete, Volume - 1: Beams, Slabs, Columns and Frames for Buildings", 2nd Edition, Blackwell Scientific Publications, Oxford, 1994.
2. Johnson R. P. and Buckby R. J., "Composite Structures of Steel and Concrete, Volume 2: Bridges", 2nd Edition, Blackwell Science, Steel Construction Institute, 1986.
3. IS: 11384, "Design of Steel-Concrete Composite Structures in General Construction" -Draft Code, Bureau of Indian Standards, New Delhi, 2022.
4. EN 1993 – 2005, "Eurocode 3: Design of Steel Structures - Part 1.1, General Rules and Rules for Buildings", European Committee for Standardization, Brussels.
5. BS 5400 – Steel, concrete and composite bridges, Part 10: Code of Practice for Fatigue", British Standards Institution, London, UK.
6. "LRFD Design Specification for Structural Steel Buildings", American Institute of Steel Construction, Inc., USA, 2001.

CORROSION IN INDUSTRIAL STEEL STRUCTURES AND MITIGATION

Pratip Bhattacharya

Manos Kumar De

Department of Civil Engineering
Tata Consulting Engineers Limited

INTRODUCTION

The subject of corrosion is associated with many aspects of various branches of chemistry, metallurgy, metal physics, and bacteriology. Scientific studies have revealed that few billions of dollars of national wealth are lost annually due to corrosion of metals of daily use. Reasons of many premature failures of metallic structures and components are due to undeterred corrosion of metal parts. With the advancement of material science, the causes and control of many aspects of corrosion have been established but even then, the corrosion science is still under investigation and will continue to be so due to the inherent complexity. The article presents a brief outline only on atmospheric corrosion of iron and steel, the most common engineering metal and the simplest form of protection by use of selective painting / organic coatings.

DEFINITION OF CORROSION

Precise definition of the process of corrosion is difficult and controversial. L. L. Sheer has given a logical definition of corrosion as a combination of processes in which a metal or alloy used as construction material is transformed from metallic to combined state during interaction with the elements of the environment. Metals are generally reactive and except for noble metals they tend to exist in nature as combined stable forms in oxides, sulphates, carbonates etc. Metal extraction processes are designed to recover the metal in pure form from these compound forms of ores, but upon exposure to environment the metals tend to revert to stable compound forms. Metals are useful in pure forms and such conversion during the use is undesirable. Corrosion is defined as the 'undesirable deterioration' of a metal. It is an interaction of the metal with the environment which adversely affects the useful properties of the metal.

It may be noted that corrosion is not detrimental in all situations. The oxidized metal coats the surface and prevents further corrosion by hindering the access of metal with oxygen.

BASIC PRINCIPLES OF CORROSION

Corrosion has been defined as the process of transformation of metal to more stable compound form. Metal atom changes to ionic form by losing electrons in natural environment where they are absorbed by other atoms. The rusting of iron takes place in presence of simultaneous presence of water and oxygen in the environment. The chemical reactions are given here.

$H_2O \rightleftharpoons H^+ + OH^-$ (1)

$Fe\ (metal) \rightleftharpoons Fe^{++} + 2e$ (2)

$2H^+ + 2e \rightarrow 2H$ atoms (3)

$2H$ atoms $\rightarrow H_2$ gas (prevalent in acidic medium) (3a)

$2H + \frac{1}{2} O_2 \rightarrow H_2O$ (3b)

$Fe^{++} + 2\,(OH)^- \rightarrow Fe(OH)_2$ (insoluble rust) (4)

Further oxidation of $Fe(OH)_2$ in presence of air or dissolved oxygen proceeds:

$4\ Fe(OH)_2 + O_2 \rightarrow 2Fe_2O_3.H_2O + H_2O$, (stable rust) (5)

Rusting of iron under wet condition will not proceed unless reaction 3b proceeds and for which presence of oxygen is essential.

Corrosion can therefore be represented through the simple chemical reaction.

$aA + bB = cC + dD$ (6)

Where,

A = Metal, B = Non-metal reactants playing as oxidants
C & D = the products of reaction.

The non-metallic reactant "B" represents the "Environment", although in a complex environment, the major constituents may play only subsidiary role in the reaction. Though atmosphere contains 78% nitrogen, its effect on atmospheric corrosion of iron and steel is negligible compared to oxygen, carbon dioxide, sulphur dioxide, and salt particles (in coastal environment). However, nitrogen plays critical role in specific cases like reaction of titanium with air at high temperatures.

TYPES OF CORROSION

Galvanic Corrosion

As illustrated earlier corrosion involves flow of electrons from the metal to moisture in atmosphere, ground, salt solution or from one part of metal surface to another at different galvanic potential. A corrosion cell is formed with the metal forming the anode end (positive potential) and the surrounding medium forms the cathode (negative potential).

Galvanic corrosion occurring between dissimilar metals is another common principle of corrosion. When such dissimilar metals are immersed in electrolyte (acidic or salt solution) and connected by wire, current flow continues till the anode metal end dissolves in the electrolyte. Table 1 lists galvanic series of metals that can form such electrode pairs. This principle is used in design of cathodic protection of steel for underground installations or in seabed. A metal with higher galvanic potential like magnesium or zinc is bonded to the steel surface. This metal forms the sacrificial anode and protects the steel by forming a coating on its surface[1].

Table 1: Galvanic Series Classification of Metals

Corroded End, Active, Anodic, Less Noble	**Protected End, Passive, Cathodic, Noble**
Magnesium	Lead
Magnesium alloys	Tin
Zinc	Nickel (active)
Aluminium 2S	Inconel (active)
Cadmium	Hastelloy C (active)
Aluminium 17 ST, Steel or iron	Brass
Chromium iron (active)	Copper
Ni-resist	Bronzes
18-8 Chromium-Nickel-Iron (active)	Copper-Nickel alloy
19-8-3 Chromium-Nickel-Molybdenum-iron (active)	Monel
	Silver Solder
	Nickel (passive)
	Inconel (passive)
	Chromium ion (passive)
	18-8 Chromium-Nickel-Iron (passive)
	19-8-3 Chromium-Nickel-Molybdenum-iron (passive)
	Hastelloy C
	Silver
	Graphite
	Gold
	Platinum

In another case of galvanic corrosion, crack in mill scale on steel surface forms galvanic couple with underlying steel and the galvanic couple is strong enough to corrode the steel below. This effect is illustrated in Figure 1. Mill scale varies in thickness from 50 microns to 5000 microns and usually consists of outer layer of stable ferric oxide (Fe_2O_3), intermediate layer of ferrosol-ferric oxide (Fe_3O_4), and unstable ferrous oxide (FeO) as innermost layer intermingled with crystalline steel structure. The unstable FeO oxidizes to ferric state with increase in volume resulting in loss of the scale layer exposing more steel surface to corrosion.

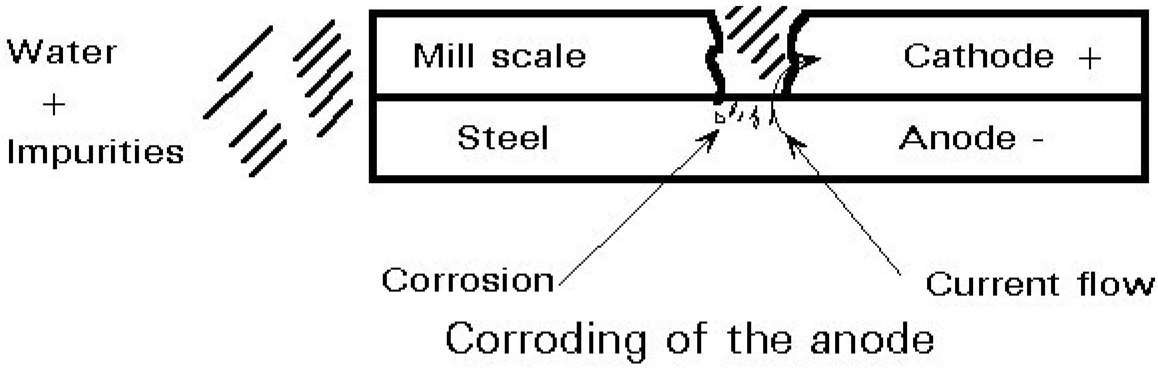


Figure 1: Corrosion Between Mill Scale and Steel[1]

Concentration Cell

Severe corrosion, leading to pitting is often caused by concentration of cells particularly where there are differences in dissolved oxygen concentrations. This type of corrosion is very common in industrial steel structures in contact with water relatively low in dissolved oxygen. The steel is anodic in areas in contact with water with higher dissolved oxygen and cathodic in areas with minimum oxygen contact. There can also be difference in metal ion concentrations in different regions of steel in contact with electrolyte that can lead to formation of electrode pair. Metal from the anodic part disintegrates from the matrix to increase ion concentration that manifests as corrosion. Typical examples are crevice corrosion due to jointing of metals or pits formed due to breakage of mill scale or coating voids. Schematic illustration for the two types of concentration cell corrosion is presented in Figure 2.

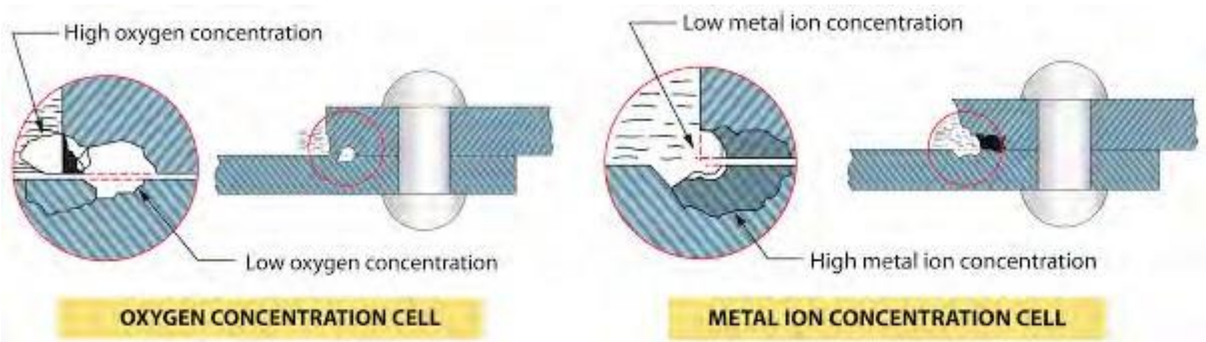


Figure 2: Concentration Cell Corrosion Mechanism[1]

Other Forms of Corrosion

There are many others forms of corrosion all of which are not discussed in detail but a summarised list of corrosion mechanisms prevalent in industrial structures is presented in Table 2.

Table 2: Corrosion Mechanisms for Steel Structures in Industrial Settings

Sl. No.	Failure Mechanism-Rank	% of occurrence
1	General Corrosion	25.8
2	Fatigue or corrosion fatigue	18.7
3	Stress Corrosion	11.7
4	Erosion Corrosion	8.7
5	Pitting	6.8
6	Weld and fabrication defects	5.0
7	Overload, mechanical abuse	4.2
8	Brittle fracture	3.9
9	Wrong material selection	3.4
10	Wear	3.2
11	High temperature oxidation or creep	1.8
12	Casting flaws	1.6
13	Crevice Flaws	1.6
14	Intergranular corrosion	1.1
15	Hydrogen Embrittlement	0.6
16	Dissimilar metals	0.5
17	Heat treatment errors	0.3
18	De alloying	0.6
19	Others	

ENVIRONMENT/EXPOSURE CONDITIONS

As discussed earlier, environment plays the governing role in initiating the corrosion. The designer tries to assess the environmental conditions before selection of specific paint system. All the environmental factors that are considered have one thing in common that is aqueous environment. Water is an important, sometimes a major constituent of such environment and plays an essential part in the corrosion process that occurs. The first environmental factor taken up for discussion in this article is water.

Water

Natural water is ultimately derived from sea water or from rainwater. The composition of seawater varies especially near large estuaries or at different depths. The main controlling parameters are dilution or pollution (both from rivers) and dissolved oxygen which varies with the depth and temperature. Rainwater usually has low probability of contact with metals except when it has a considerable bearing on atmospheric corrosion. Dissolved gases in water is another factor that controls the corrosion process. Carbon dioxide that remains uncombined in solution is a frequent source of corrosion for structures in contact with water. Dissolved oxygen is almost always present in sufficient quantity to be important. Traces of a few parts per million oxygen in the purest of water can accelerate corrosion. It is the environment in the immediate vicinity of the metal surface that counts as far as corrosion is concerned.

In de- aerated natural water, the rate of corrosion may be usually high due to the presence of sulphate reducing bacteria in water. The bacteria only thrive in the absence of Oxygen and within the pH range of about 5.5 to 8.5. This type of corrosion of is generally seen in buried pipelines of deep-water wells and casing of oil Wells.

Soils

The next environment to which structures are exposed is soil. Here the water is held in the soil structure in many complex ways and contains a wide variety of corrosive ingredients. The soil itself may consist of sand, clay, chalk, decomposed organic matters and other minerals / chemicals. The soil may be well aerated or relatively air free; the soil water level may be permanently above or below the buried metal. Further if the electrical resistivity of the soil is low, the localized corrosion will accelerate and spread due to low electrical resistance. The protection system by paints or coatings will not suffice - cathodic protection by using impressed current or sacrificial anode in most cases are adopted along with other options.

Chemical Environment

There are endless variety of aqueous environments to which metals are exposed in process plants. The most common corrosion chemicals are acids, chlorides, salt, particularly oxidizing salt which take away the free electrons from metal surface and is difficult to prevent or stop completely.

Atmosphere

This is the most common environment to which plants and equipment are exposed in some form or other. Air itself is not particularly corrosive to the main structural metals. In clean air steel is attacked very slowly even if the air is moist. It would take 70 years to fully corrode steel plate of 3 millimeters thickness if located in rural atmosphere and can go up to thousand years in hot dry climates. In salt laden area in marine environments and especially in the immediate vicinity of the coast much higher rates of attack becomes common. Examples of these higher corrosion rates are given in Table 3[1].

Table 3: Atmospheric Corrosion Rate (Microns) for One-Year Exposure to Sea Salt[6]

Distance from Surface (metres), apprx.	Corrosion rate microns / yr. – Ingot Iron	Corrosion rate microns / yr. – Zinc	Salt Content in air (ref 1)
50	38	1.5	11.1
200	15	0.6	3.1
400	2.2	0.1	0.8
1300	1.6	0.02	-0.2
3000	-	-	

Note: Salt contents expressed as mg NaCl/day/100 m^2 cloth area

The most serious cause of atmospheric pollution is from manmade polluting environment. Atmospheric pollution from burning of fossil fuels and from other industrial processes, makes all the structural metals corrode more rapidly. Presence of water in some form is necessary, even if the relative humidity is shown below 100 %, many common metals particularly iron and steel are found to corrode. It is certain that at a given temperature there is a critical humidity for metals such as steel, copper, zinc etc. above which corrosion is considerably increased especially when pollutants like SOx / NOx, and/or sea salts are present.

In summary, the designer must go in depth for the correct assessment of the environment in which designed metal atoms are exposed. The basic classes of environment are as listed below.

Dry
Tropical
Rural
Humid
Temperate
Urban
Marine
Arctic
Industrial

A site can be a combination of these basic environment classes. In case of a structure located in marine tropical industrial environment it is easy to understand its corrosion severity. ISO 12944 classifies environment into five lasses based on the exterior condition and impact on structural components as shown in Table 4.

ROLE OF PAINTING IN CORROSION PREVENTION

The use of paints and industrial coatings is the most common way to control a large segment of the general atmospheric corrosion. Industrial paintings can provide superior resistance against corrosive environment, chemicals, water, temperature, and abrasion.

Table 4: Corrosion Class and Environment (Internal/External)[6]

Class	Impact	Interior	Exterior
C1	Very low	Heated buildings with clean air, such as offices, shops, schools, hotels, etc.	None
C2	Low	Buildings not heated, where condensation may occur, such as warehouses and sports halls.	Atmosphere with low pollution e.g., in the country.
C3	Middle	Buildings for production with high atmospheric humidity and some air pollution such as food manufacturers, breweries, dairies and laundries.	Urban and industrial areas, moderate sulphur dioxide pollution. Coastal areas with low salt content.
C4	High	Chemical manufacturers, swimming baths and ship- and boatyards by the sea.	Industrial areas and coastal areas with moderate salt impact.
C5-I	Very high - Industry	Buildings or areas with almost permanent condensation and with high pollution.	Industrial areas with high humidity and aggressive atmosphere.
C5-M	Very high	Buildings or areas with almost permanent condensation and with high pollution.	Coast and offshore areas with high salt content.

Action of Paint

Paint is a mixture of pigment which gives opacity and a liquid binder material (vehicle) which binds the pigments together. The purpose of paint coat is to protect the metal surface from its environment.

Paint retards the corrosion of steel in number of ways:

i. Paint forms more or less an impervious barrier between the metal surface and the surrounding environment. This mechanical barrier is not totally impervious. Even with the best paint products and best method of application there will be pores through which moisture and air / gases will diffuse to corrode the metal. Therefore, application of multiple coats is adopted to hinder the diffusion process.

ii. It is well known that certain chemical compounds either completely stop or retard the corrosion of the steel. It is understood that these compounds form films on the anodic or cathodic area which lead to the suppression of the corrosion. For example, chromate salts can easily be leached away; therefore, less soluble zinc chromate pigments find use as rust inhibitor. Zinc phosphate pigment which is occupationally safest rust inhibitor pigment is used extensively for primer paint formulations. Similarly, red lead (lead oxide) pigment when dispersed with linseed oil and alloyed to dry form lead soaps which form a dense rough film of very low water permeability.

iii. Corrosion is an electrochemical process where electric current from anode (corroding metal) to cathodic area or environment causes metal to corrode away. Paint films formed due to polymerisation of organic vehicle act as insulating membrane which disrupts the flow of electrical current if the film is intact.

In summary, it might be stated that a suitable metal protective paint must be one with rust inhibitive properties, low permeability to corrosive agents, low absorption of water and the ability to wet the surface to which it is applied. In special cases the paints should have fire retardant properties when the installation is prone to fire hazard.

Performance of Paint System

The important factors which govern the desired performance of an industrial paint system are:

i. Proper design of the structure / equipment to be painted and the appropriate selection of the material which can withstand the environment. If the selection of basic engineering material is inappropriate with respect to the environment, the paint alone cannot protect the metal; paint at best retards the corrosion rate but cannot stop the process.

ii. Correct assessment of the likely exposure conditions and the operating temperature of the surface to be painted. Corrosion rates generally increase with rise in temperature, but presence of oxygen also plays crucial role in controlling the rate[7].

iii. Location of the structures / equipment – indoor or outdoor installation.

iv. Whether the structure / equipment are underground or over ground or immersed in water; in case of immersion in water, the water quality and existence of any splashing zone where the structure undergoes alternate cycles of wetting and drying need to be assessed.

v. Selection of specific paint system for specific environmental consideration.

vi. Proper surface preparation and formulation and application of paint

vii. Monitoring of paint condition and timely maintenance of painting by touch-up and re-painting.

CORROSION IN STEEL PLANT AND CORROSION PROTECTION COATING SYSTEM

The following case study is from a typical environment in Steel Plant. Table 5 identifies the plant area, corrosion zone and the corrosion rate. Steel plant atmosphere have high dust loads and these tend to settle on structural members. The accumulated dust contains polluting chemicals and absorbs moisture from air or gets wet in rain. This mixture aggravates the corrosion process in the steel structure. Table 6 shows anticipated dust accumulation in various areas of steel plant.

Table 5: Areas of Steel Plant with Corrosion Rates

Sl. No.	AREA / PLANT	ZONES	Corrosion Rates (mils per year)
1.	Rolling Mill area, Engg. Work Shops, Raw Material Area	Normal Corrosive Zone.	Corrosion rate less than 1 mpy
2.	E.T.P. Area, SMS Area, Captive Power Plant Area	Mild Corrosive Zone.	Corrosion rate between 1 & 3 mpy
3.	Coke Oven area, Coke Plant By-Product Area	Corrosive Zone.	Corrosion rate between 3 & 5 mpy
4.	Pig Casting Machine Area, Pickling Mill area.	Highly Corrosive Zone.	Corrosion rate of 5 mpy & above

Paint System

A paint film forms only mechanical bondage with the virgin metal surface. The surface should be artificially prepared to provide anchoring profile for the paint film. Application of paint on the rusted metal surface or on greasy surface the paint will not hold. Up to 70 % of coating failure have been blamed on poor surface preparation. There are various methods of surface preparation like wire brushing, power tool cleaning, or shot blasting, chemical cleaning (pickling) that is quickly and even flame cleaning depending on degree of cleanliness desired. degree of cleanliness of Steel surface represents as St. 1 to St. 3 and Sa1 to Sa3 are pictorially represented in Swedish Standard S/S 055900.

The anti-corrosive paint system comprises of following:

Prime Coat

Prime coats are the initial basic coats to be applied preferably by brush on the freshly prepared steel surface. Primers provide adhesion to the metal plus corrosion control to protect it. There are three main types of primers

barrier primers

inhibitor primers

zinc rich primers

Table 6: Dust Deposition in Steel Plant Areas

DUST DEPOSITION in ISP				
Location	Type of Dust	Deposition rate per year (Thickness in mm)	Density (Kg/Cu.M)	Remarks
SMS	Iron	75mm and more	1700	Irone Fines
Lime Calcining Plant	Lime	100 and more	1300	Lime, Dolo etc
Sinter Plant	Sinter	100mm and more	1850	Sinter Mix
Captive Power Plant	Coal/Ash	50mm and more	870 1000	Coal Dust Fly Ash
Blast Furnace	Iron Ore / Sinter	300mm and more	2400 1850	Iron Ore Sinter
Raw material	Iron	75mm and more	1700	Various Raw Materials including Iron
Coke Ovens	Coal/Coke	300mm and more	870 750	Coal Dust Coke Dust

Note:

1. . Table formed based on experience and various interactions with plant personnel
2. . The accumulated thickness is indicative, can be bettered with proper maintenance

Barrier primers are impermeable films such as vinyls, chlorinated rubber, epoxies etc. these primers reduce the access of water, chlorides, and sulphates to the Steel. They impart corrosion resistance by artificially increasing the electrical resistance of the corrosion cell. Barrier primers are most favoured where there is continuous exposure to corrosive electrolytes such as Marine installations, chemical installations, water storage tanks or buried pipelines.

Inhibitive primers are commonly composed of oil base, alkalyds of phenolic alkalyd vehicle that contains small additions of soluble inhibitors such as chromates, molybdates etc. These inhibitor chemicals dissolve as moisture diffuses through the paint system to the Steel surface. The inhibitor then retards the electrochemical corrosion reactions at the microscopic anodic or cathodic areas on the steel surface.

Zinc rich primers are highly loaded with metallic zinc e.g., 86 % by weight. The zinc sacrificially corrodes to protect the steel which acts as non-corroded cathode. Zinc-rich Primers protect against corrosive undercutting of paint system and in additions offers good abrasion resistance.

There are other organic (e.g., epoxy) and inorganic (e.g., ethyl silicate) zinc rich primers. Organic zinc rich primers can tolerate slightly poorer surface preparation quality and easier to apply than inorganic ones. chemical resistant wise organic zinc rich primer is better than inorganic based. However, dry heat resistance for organic primer is limited to 120° Celsius to 150° Celsius for the inorganic primers.

In outdoor exposure or other environment, essentially in neutral pH condition the inorganic zinc primers can be left without top finish coat (ignoring aesthetics). However, if the pH of the environment is below 5 or above 10, untop-coated zinc rich increase primers are favoured for shop priming of steel that is slated for use in severely corrosive environment such as continuous or intermittent immersion of seawater or for long outdoor life. Zinc rich primers have been called the "ultimate contribution of the paint technologies to the work on corrosion".

Top Coat

The role of the topcoat is to

I. protect the primers from weathering
II. provide the protection as listed in the Table 7[8]
III. provide aesthetics including long lasting colour and gloss preferably without excessive chalking, fading, or yellowing.

Relative resistance of different types of top quotes against various types of environment is given in Table 7.

Paint Film Thickness

Enough paint must be applied for corrosive environment and is usually a minimum of three coats with the total dry film thickness that is DFT of at least 125 microns. In one comparison for structures in steel plant exposure, it is reported that oil-based coatings of 100 to 125 micron give 8 to 10 years of protection in rural environment whereas for marine environment the coating need to build more, minimum 220 microns for oil-based paint, 125 microns for alkalyds, 115 microns for epoxy and 120 microns for chlorinated rubber and 75 micron for vinyl if 8 to 10 years protection are desired.

High Build coatings of thickness DFT 50 to 75 microns per coat provide an economical means of adding more microns for application but are not as protective as regular build coating applied in several coats to give an equivalent film thickness.

Compatibility of Paint System

This is a very important aspect while recommending a paint system. All paints are not compatible which means by selection of any specific paint as a primer the top coat cannot be chosen at random. With alkali primer epoxy top coat is not compatible as if it will chemically decompose the epoxies. There are similar such incompatibilities with many paints.

Table 7: Relative resistance of common topcoat paints to exposure[8]

Paint	Acids	Alkalis	Salts	Solvents	Water	Weather	Oxidation	Abrasion
Oil Based	1	1	6	2	7	10	1	4
Alkyd	6	6	8	4	8	10	3	6
Chlorinated rubber	10	10	10	4	10	8	6	6
Coal tar epoxy	8	8	10	7	10	4	5	5
Epoxy - amine /amide	9	10	10	9	10	8	6	6
Silicon Alkyd	4	3	6	2	8	8	6	6
Vinyl	10	10	10	5	10	10	10	7
Urethane	9	10	10	9	10	8	9	10
Zinc (inorganic)	1	1	5	10	5	10	10	10

Note: A value of 10 represents the best protection.

Specifying a suitable painting system for steel structure should address the following aspects at minimum:

1. assessment of the environment
2. selection of right paint system
3. surface preparation standard
4. method of application including number of coats / paint thickness
5. drying time and coating intervals
6. crucial application limitations
7. strict observance of the maker's directions
8. safety precautions
9. clean up
10. inspection and quality control

Paint Failure

Despite design and application of the best paint system the paint film is susceptible to fail for various reasons some of which are listed below.

i) Faulty mechanical design of the structures and equipment by which the surface contours are such that uniform coating thickness cannot be developed.

ii) Improper application of paint, most of the defects in an applied paint which do not stem from improper surface preparation but from incorrect mixing of paint ingredients or application in a hurry without waiting for drying.

iii) Incorrect paint formulations or old paints in use

iv) Loss of adhesion

v) Application of paint in humid weather

vi) Mechanical stresses and other abuses on the paint film

vii) Under film corrosion - this occurs most readily when the coated metal is exposed in high humidity environment (50 - 200 % R.H>) and situation becomes worse if the environment is saline as in the case of marine environment. It can be retarded if the relative humidity of the environment is maintained at less than 50 %, if an inhibitor is added to the paint or if the reactivity of the metal surface is decreased by means of metal surface treatments that form on the substrate metal a compound of the metal (e.g., a phosphate or an oxide) that is less reactive than the bare metal.

It is thus mandatory to chalk out a regular paint and structure health inspection plan and carry out periodic checks and maintenance of the paint coatings throughout the service life of the structure.

MAINTENANCE OF PAINTING

If the engineering structures and equipment need to be protected from corrosion, the protection measures adopted need equal maintenance care as plant and machinery. It is more important to have regular maintenance on retaining the paint film than to replace the entire metal badly affected by corrosion.

In all maintenance painting the aim is to repaint before the old paint has deteriorated to a stage where it must be entirely removed. This is done by periodically applying a single new coat of paint over the cleaned old paint substrate. The normal span of such a period for a marine installation should be around 2 years both for outside and inside painting if required.

In maintenance painting it is not intended that sound, adherent old paint system be removed unless it is excessively thick or brittle or is incompatible with the new paint. However, the defective paint layer shall be removed beyond the edges of the defect spot or area till a zone of intact and perfectly adherent paint layer without rust or blister below the film is reached. The retained part of old paint zone should have adequate adherence to prevent it getting lifted as a layer when putty knife is inserted under the coating. The edges of adherent paint coat outside the defective area are feathered to create a gradual taper towards the zone of recoating to create smooth overlap zone. For defective areas of old paint substrate, work involves spot cleaning to provide new anchoring profile and application of adequate number of coats of compatible primer over those areas is carried out to build them up to a satisfactory level. Then an overall finish coat is applied as final coat.

Today everybody is aware that timely remedial measures against corrosion would not only save the huge expenditure in replacing the corroded defunct equipment / steel structure by new one but also of the production shut down time can be reduced. In recent times computers have been deployed to compile systematically all sorts of corrosion data, results of corrosion preventive measures and predict future plan of action to combat the corrosion.

CONCLUSIONS

Steel / Steel Structure is subjected to degradation by corrosion. Corrosion is a natural phenomenon which occurs in simultaneous presence of water and oxygen (air). However, rate of corrosion is not uniform everywhere. There are several factors which influence the rate of corrosion. Rate of corrosion can be minimized but can't be eliminated. Corrosion is controlled by changing the environment, though it is difficult. Rather it is easier when protective system is adopted. Painting is the best method of preventing corrosion in steel structure. However, its effectiveness is depending on many factors. However, steel structure can last more than 100 years with application of proper protective maintenance painting.

REFERENCES

1. http://fgg-web.fgg.uni-lj.si/~/pmoze/esdep/master/wg04a/l0100.htm
2. https://www.corrosionpedia.com/
3. . https://www.aircraftsystemstech.com/2019/04/forms-of-corrosion-aircraft-corrosion.html
4. . Date R. McIntyre, "Evaluating the Cost of Corrosion Control Methods", Chemical Engineering, April 5, 1982, P-127.
5. . I. A. Menzies, E. C. Potter, C. Edeleanu and J. F. Stanners, "Corrosion and Protection of Metals", Iliffe Books Ltd., London
6. . ISO 12944-2018, "Corrosion protection of steel structures by protective paint systems", International Organizationfor Standardization, Switzerland.
7. . https://mti.memberclicks.net/assets/documents/TAC-Bulletins/Non-Member-Egnlish/Bulletin%2013%20-%20non-member%20English.pdf
8. . Gary N. Kirby, "What You Need to Know About Maintenance Painting-Part I", Chemical Engineering, 75-78 (July 26, 1982)
9. . In-house training lecture notes by Engineer Mr. K. B. Deb
10. . Blog notes shared by Dr. N. Subramanian

HIGH STRENGTH STRUCTURAL STEEL

Asim Kumar Samanta
General Manager (Mechanical)
Institute for Steel Development & Growth

INTRODUCTION

Steel, Concrete and Wood are the three popular materials for constructing structure such as Bridges, Buildings and Stadiums etc. Steel is preferred for its high strength to weight ratio. Concrete is popular for its easy availability in small quantity and easy casting procedure. Woods are becoming scarce now-a-days.

Steel is a very important material for making structure. Because of its high strength to weight ratio, steel structure is slim and elegant. It occupies less space and offer high durability. Mild steel (yield strength <350 MPa) is the most common type of steel used for making structure. Obviously, more the strength of steel, more elegant is the structure. However, this concept does not match with the Indian construction scenario. High strength steel (yield strength > 400 MPa), though popular in developed countries, is comparatively new product in India. High-strength low-alloy steel (HSLA) steel is an alloy steel that provides better mechanical properties or greater resistance to corrosion than carbon steel. HSLA steels are not made to meet a specific chemical composition but rather to specific mechanical properties.

Steel is strong in tension requires special arrangement of sections when it is subjected to compression. Concrete is strong in compression but very week in tension. Steel Reinforcement is given in concrete when it is subjected to tension. In this case, concrete is better known as Reinforced Concrete (RCC).

Steel is produced in industry and it is compound materials. Ensuring quality in steel is easier. Concrete is mixed materials prone to non-homogeneity of quality.

Steel, being a compound and industry made products offer wide variety of properties and applications – both structural and non-structural.

STEEL

Steel is an alloy of Iron and Carbon. But it has alloying elements such as Manganese, Phosphorus, Silicon and Sulphur. Many other alloying elements are added for achieving any specific property required for a particular application.

STRUCTURAL STEEL

Steel, when used to construct structure, is known as Structural Steel. Yield Stress, Maximum Tensile Stress, Elongation, Toughness and Weldability are important properties of steel. Addition of Carbon into steel increases the strength of steel but it decreases elongation and weldability. This phenomenon limits the strength of steel for structural application.

Structural Steel in India has been specified mainly by following two codes / standards:

1. . IS 15911 : 2010 [Structural Steel (Ordinary Quality) - Specification] [1]
2. . IS 2062 : 2011 (Hot Rolled Medium and High Tensile Structural Steel - Specification) [2]

Chemical Compositions and Mechanical properties of different grades of structural steel are given in Table 1, Table 2, Table 3 and Table 4.

Table 1: Chemical Composition of Structural Steel as per IS 15911 : 2010

Sl No.	Grade Designation	Ladle Analysis, Percent, *Max*			
		C	Mn	S	P
(1)	(2)	(3)	(4)	(5)	(6)
i)	E165	0.25	1.25	0.060	0.075
ii)	E170				
iii)	E215				

Table 2: Mechanical Properties of Structural Steel as per IS 15911 – 2010

Sl No.	Grade Designation	Tensile Strength R_m *Min* MPa	Yield Stress R_{eH} *Min* MPa	Percentage Elongation, *A* at Gauge Length, L_o $5.65\sqrt{S_o}$ *Min*	Internal Bend Diameter
(1)	(2)	(3)	(4)	(5)	(6)
i)	E 165	290	165	23	$2t$
ii)	E 170	330	170	23	$3t$
iii)	E 215	370	215	23	$3t$

It has been observed that structural steel having strength range from 165 N/mm^2 to 650 N/mm^2 have been specified in the standards.

In addition to above-mentioned two standards, another two standards of structural steel are published for specific application as mentioned in the respective title but these are in lesser use as these are not included in the IS: 800 – 2007 (General Construction in Steel - Code of Practice)[3] overtly.

1. . IS 11587 – 1986 (Specification for Structural Weather Resistant Steels)[4]
2. . IS 15103 - 2002 (Fire Resistant Steel — Specification)[5]

In the above-mentioned two standards, structural steel of strength range from 240 N/mm^2 to 350 N/mm^2 has been specified.

Table 3: Chemical Composition of Structural Steel as per IS 2062 : 2011

Grade Designation	Quality	Ladle Analysis, Percent, *Max*					Carbon Equivalent (CE), *Max*	Mode of Deoxidation
		C	Mn	S	P	Si		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
E 250	A	0.23	1.50	0.045	0.045	0.40	0.42	Semi-killed/killed
	BR B0	0.22	1.50	0.045	0.045	0.40	0.41	Semi-killed/killed
	C	0.20	1.50	0.040	0.040	0.40	0.39	Killed
E 275	A	0.23	1.50	0.045	0.045	0.40	0.43	Semi-killed/killed
	BR B0	0.22	1.50	0.045	0.045	0.40	0.42	Semi-killed/killed
	C	0.20	1.50	0.040	0.040	0.40	0.41	Killed
E 300	A BR B0	0.20	1.50	0.045	0.045	0.45	0.44	Semi-killed/killed
	C	0.20	1.50	0.040	0.040	0.45	0.44	Killed
E 350	A BR B0	0.20	1.55	0.045	0.045	0.45	0.47	Semi-killed/killed
	C	0.20	1.55	0.040	0.040	0.45	0.45	Killed
E 410	A BR B0	0.20	1.60	0.045	0.045	0.45	0.50	Semi-killed/killed
	C	0.20	1.60	0.040	0.040	0.45	0.50	Killed
E 450	A BR	0.22	1.65	0.045	0.045	0.45	0.52	Semi-killed/killed
E 550	A BR	0.22	1.65	0.020	0.025	0.50	0.54	Semi-killed/killed
E 600	A BR	0.22	1.70	0.020	0.025	0.50	0.54	Semi-killed/killed
E 650	A BR	0.22	1.70	0.015	0.025	0.50	0.55	Semi-killed/killed

HIGH STRENGTH STUCTURAL STEEL

Structural steel having Yield Strength more 400 MPa is understood to be High Strength structural steel. As high strength steel is preferred to for construction of structure with the assumption that structure built with high strength steel will make self-weight of structure comparatively less and it will result into cost of structure cheaper. But this simple assumption may not be true always because price of high strength steel is more comparatively. There are technical reasons too for limited use of high strength steel. It is described here.

Deflection of members of structure is limited by the Clause No.5.6.1 (Limit State of Serviceability) of IS 800 – 2007 which is some fraction of length / height of member. Formula used for calculation of deflection indicate that amount of deflection does not depend on strength of material. It increases when Load Applied and Length of member increase and it decrease when Moment of Inertia and Modulus of Elasticity increase. Modulus of Elasticity for steel is assumed to be constant irrespective of strength of steel. Therefore, high strength of steel is not effective for using when it is restricted by Deflection Limit.

Therefore, high strength steel should be used where deflection is not the limiting criteria. Use of high strength steel is advantageous where members are subjected to only tensile stress – commonly understood as Tensile Structure.

Table 4: Mechanical Properties of Structural Steel as per IS 2062 – 2011

Grade Designation	Quality	Tensile Strength R_m, *Min* MPa[1)] (*See* Note 1)	Yield Stress R_{eH}, *Min* MPa[1)]			Percentage Elongation *A*, *Min* at Gauge Length, L_o=5.65	Internal Bend Diameter *Min* (*See* Note 2)		Charpy Impact Test (*See* Note 3)	
			<20	20-40	>40		≤25	>25	Temp °C	*Min* J
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
E 250	A	410	250	240	230	23	2*t*	3*t*	—	—
	BR								RT	27
	B0								0	27
	C								(–) 20	27
E 275	A	430	275	265	255	22	2*t*	3*t*	—	—
	BR								RT	27
	B0								0	27
	C								(–) 20	27
E 300	A	440	300	290	280	22	2*t*	—	—	—
	BR								RT	27
	B0								0	27
	C								(–) 20	27
E 350	A	490	350	330	320	22	2*t*	—	—	—
	BR								RT	27
	B0								0	27
	C								(–) 20	27
E 410	A	540	410	390	380	20	2*t*	—	—	—
	BR								RT	25
	B0								0	25
	C								(–) 20	25
E 450	A	570	450	430	420	20	2.5*t*	—	—	—
	BR								RT	20
E 550	A	650	550	530	520	12	3*t*	—	—	—
	BR								RT	15
E 600	A	730	600	580	570	12	3.5*t*	—	—	—
	BR								RT	15
E 650	A	780	650	630	620	12	4*t*	—	—	—
	BR								RT	15

WELDABILITY OF HIGH STRENGTH STUCTURAL STEEL

In addition to the restricted use of high strength steel caused by limited deflection, weldability is another deterrent for using high strength steel in structure.

In 1940, Dearden and O'Neil [6] have recommended the relationship between chemical compositions of steel and hardness of steel in the HAZ after welding. This is given by:

Maximum Vickers Hardness Number $(H_V) = 1200CE_{Dearden} - 200$

Where, Carbon Equivalent $(CE_{Dearden}) = C + \frac{P}{2} + \frac{Mn}{6} + \frac{Cu}{13} + \frac{Ni}{15} + \frac{Cr}{5} + \frac{Mo}{4} + \frac{V}{5}$

It is believed that if HAZ hardness of steel is less than 350 HV, no cold-cracking would occur after welding but if the HAZ hardness is greater than 400 HV, the steel would be prone to cold-cracking. It is known that welding is very important joining method for constructing a steel structure. Weldability is the ease of welding by with two members can be joined without any crack or any other defect.

In 1970, Bastien [7] has found the relationship between critical cooling rate, CR_M (maximum time required by unstable austenite to be transformed into martensite) and carbon equivalent as given below:

$$ln(CR_M) = 13.9 - 10.6\, CE_{BastBBen}$$

$$CE_{BastBBen} = C + \frac{Mn}{4.4} + \frac{Ni}{10.3} + \frac{Cr}{15 \cdot 4} + \frac{Mo}{7 \cdot 7}$$

It should be noted that welding in structure is carried out in hot condition (more than 723 ^{0}C temperature) which allow re-crystallization in steel. Quick cooling helps to form Mertensite micro-structure which has hardness of more than 400 HV, indicating the welding is prone to crack during service of the structure.

Therefore, it is concluded that Carbon Equivalent is indicator of weldability of steel.

It is experienced by welding personnel that if Carbon Equivalent (CE) is more than 0.45, the steel is very difficult to weld. In this case, Carbon Equivalent is calculated by the following formulae.

$$CE = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Ni + Cu}{15}$$

Carbon Equivalent of E410 Grade steel produced as per IS 2062 – 2011 is 0.50. Therefore, welding of this steel is difficult. Difficulty in welding of high strength steel can be eased a little by following methods:

Preheating of steel before welding

Slowing the Post-Welding-Cooling to such a level that micro-structure of steel would be anything other than Martensite.

Micro-alloying of steel in such a way that Carbon Equivalent of steel will be less than 0.5.

Out of the three methods mentioned above, Preheating of steel and lowering the post-welding cooling rate depend on the skill of welder as well as the workshop / environment where the welding is being carried out.

However, the problem can be solved in a better way if High Strength Low Alloy Structural Steel is produced with lower Carbon Equivalent.

HIGH STRENGTH LOW ALLOY STRUCTURAL STEEL

IISI (International Iron and Steel Institute) classify the steel as High Strength Structural Steel when the structural steel contains maximum 0.2% carbon and up to 2.5% alloying elements by weight.

Structural Steel having more than 400 MPa Yield Strength specified in IS 2062 – 2011 is not truly High Strength Low Alloy Steel as per IISI classification. However, many think that the High Strength Steel is micro-alloyed because of Note No. 5 and Note No. 6 given in the code as stated below:

Note No.5 Micro-alloying elements like Nb, V and Ti may be added singly or in combination. Total micro-alloying elements shall not be more than 0.25 percent.

Note No.6 Alloying elements such as Cr, Ni, Mo and B may be added under agreement between the purchaser and the manufacturer. In case of E 600 and E 650 the limit of Cr and Ni, either singly or in combination, shall not exceed 0.50 percent and 0.60 percent respectively.

As both the Notes make the micro-alloying optional, no high strength micro-alloyed steel is produced in India in reality. In India, hardly there is any scope for a consumer to discuss about the chemical composition of steel with producers.

In this context, EN 10025 [8, 9, 10, 11, 12, 13], the standards for specification steel can be referred to. It has six parts with following descriptions:

Part 1: Hot rolled products of structural steels - General technical delivery condition

Part 2: Technical delivery conditions for non-alloy structural steels

Part 3: Technical delivery conditions for normalized / normalized rolled weldable fine grain structural steels

Part 4: Technical delivery conditions for thermo-mechanical rolled weldable fine grain structural steels

Part 5: Technical delivery conditions for structural steels with improved atmospheric corrosion resistance

Part 6: Technical delivery conditions for flat products of high yield strength structural steels in the quenched and tempered condition

It can be seen that classification and specification of steel are easily understandable and more scientific. Steel specified in Part 2 of EN 10025 is non-alloyed but steel specified in Part 3 of EN 10025 is micro- alloyed steel. High Strength steel specified in Part 3 is weldable and weldability has been improved because it is fine grained steel. The chemical composition and mechanical properties of steel specified in EN 10025 (Part 3) are given in Table 5 and Table 6 respectively.

Table 5: Chemical Composition of Structural Steel Specified in EN 10025 – 2004 (Part 3)

Designation		C % max.	Si % max.	Mn %	P % max. [a]	S % max. [a b f]	Nb % max.	V % max.	Al_{total} % min. [c]	Ti % max.	Cr % max.	Ni % max.	Mo % max.	Cu % max. [d]	N % max.
According EN 10027-1 and CR 10260	According EN 10027-2														
S275N	1.0490	0,18	0,40	0,50 - 1,50	0,030	0,025	0,05	0,05	0,02	0,05	0,30	0,30	0,10	0,55	0,015
S275NL	1.0491	0,16			0,025	0,020									
S355N	1.0545	0,20	0,50	0,90 - 1,65	0,030	0,025	0,05	0,12	0,02	0,05	0,30	0,50	0,10	0,55	0,015
S355NL	1.0546	0,18			0,025	0,020									
S420N	1.8902	0,20	0,60	1,00 - 1,70	0,030	0,025	0,05	0,20	0,02	0,05	0,30	0,80	0,10	0,55	0,025
S420NL	1.8912				0,025	0,020									
S460N [e]	1.8901 [e]	0,20	0,60	1,00 - 1,70	0,030	0,025	0,05	0,20	0,02	0,05	0,30	0,80	0,10	0,55	0,025
S460NL [e]	1.8903 [e]				0,025	0,020									

Steel gets cooled as it is rolled, with a typical rolling finishing temperature of around 750°C. Steel is then allowed to cool naturally is termed 'as- rolled' steel and "As Rolled" Structural Steel is specified in Part 2. Normalizing takes place when as-rolled material is heated back up to approximately 900 °C, and thenheld at that temperature for a specific period time, before being allowed to cool naturally. The process of normalizing refines the grain size of steel and improves the mechanical properties, specifically toughness and improves weldability as well.

The process for Quenched and Tempered steel starts with a normalized material at 900°C. It is rapidly cooled or 'quenched' to produce steel with high strength and hardness, but low toughness. The toughness is restored by reheating it to 600°C, maintaining the temperature for a specific time, and then allowing it to cool naturally (Tempering).

Table 6: Mechanical Properties of Structural Steel Specified in EN 10025 – 2004 (Part 3)

Designation		Minimum yield strength R_{eH} [a] MPa[b] Nominal thickness mm								Tensile strength R_m [a] MPa[b] Nominal thickness mm			Minimum percentage elongation after fracture[a] % $L_0 = 5.65 \sqrt{S_0}$ Nominal thickness mm					
According EN 10027-1 and CR 10260	According EN 10027-2	≤ 16	> 16 ≤ 40	> 40 ≤ 63	> 63 ≤ 80	> 80 ≤ 100	> 100 ≤ 150	> 150 ≤ 200	> 200 ≤ 250	≤ 100	> 100 ≤ 200	> 200 ≤ 250	≤ 16	> 16 ≤ 40	> 40 ≤ 63	> 63 ≤ 80	> 80 ≤ 200	> 200 ≤ 250
S275N S275NL	1.0490 1.0491	275	265	255	245	235	225	215	205	370 to 510	350 to 480	350 to 480	24	24	24	23	23	23
S355N S355NL	1.0545 1.0546	355	345	335	325	315	295	285	275	470 to 630	450 to 600	450 to 600	22	22	22	21	21	21
S420N S420NL	1.8902 1.8912	420	400	390	370	360	340	330	320	520 to 680	500 to 650	500 to 650	19	19	19	18	18	18
S460N S460NL	1.8901 1.8903	460	440	430	410	400	380	370	-	540 to 720	530 to 710	-	17	17	17	17	17	-

CONCLUSION

High Strength Structural Steel may be used with proper design to get advantage of high strength. Weldability is a deterrent for its use. To make the high strength steel, welding skill and infrastructure need to be improved on fabricator's part whereas producing the high strength steel with proper alloying is the responsibility of steel producers.

Before all of these to happen, Bureau of Indian Standards needs to revise all relevant standards.

REFERENCES

1. . IS 15911 : 2010, "Structural Steel (Ordinary Quality) – Specification", Bureau of Indian Standards, New Delhi, India
2. . IS 2062: 2011 , "Hot Rolled Medium and High Tensile Structural Steel-Specification," Bureau of Indian Standards, New Delhi, India.
3. . IS: 800 – 2007 , "General Construction in Steel - Code of Practice", Bureau of Indian Standards, New Delhi, India.
4. . IS 11587 – 1986, "Specification for Structural Weather Resistant Steels", Bureau of Indian Standards, New Delhi, India
5. . IS 15103 – 2002, " Fire Resistant Steel — Specification", Bureau of Indian Standards, New Delhi, India

6. . J. Dearden and H. O'Neil, Transaction of the Institute of Welding, Vol. 3, 203-214 (1940), UK.

7. . P. G. Bastien, Metal Construction and British Welding Journal, Vol. 49, No.9 (1970), UK.

8. . EN 10025: 2004, "Hot Rolled Products of Structural Steels, Part 1: Hot rolled products of structural steels - General technical delivery condition", European Committee for Standardization, Brussels

9. . EN 10025: 2004, "Hot Rolled Products of Structural Steels, Part 2: Technical Delivery Conditions for Non-Alloy Structural Steels", European Committee for Standardization, Brussels.

10. . EN 10025: 2004, "Hot Rolled Products of Structural Steels Part 3: Technical Delivery Conditions for Normalized / Normalized Rolled Weldable Fine Grain Structural Steels", European Committee for Standardization, Brussels.

11. . EN 10025: 2004, "Hot Rolled Products of Structural Steels Part 4: Technical Delivery Conditions for Thermo-Mechanical Rolled Weldable Fine Grain Structural Steels", European Committee for Standardization, Brussels.

12. . EN 10025: 2004, "Hot Rolled Products of Structural Steels Part 5: Technical Delivery Conditions for Structural Steels with Improved Atmospheric Corrosion Resistance", European Committee for Standardization, Brussels.

13. . EN 10025: 2019, "Hot Rolled Products of Structural Steels Part 6: Technical Delivery Conditions for Flat Products of High Yield Strength Structural Steels in the Quenched and Tempered Condition", European Committee for Standardization, Brussels.

EFFICIENT CONSTRUCTION WITH STEEL WELD MESH FABRIC

Dr Jayanta Kumar Saha

Director
S J Engineers & Consultants, Kolkata

Visiting Professor (Calcutta University)

INTRODUCTION

Construction sector is one of the fastest growing sectors in the world contributing largely towards industrial and economic growth. Observing similar stature in India, it is considered as one of the core industries contributing significantly to the economy of India. In the last decades the sector has shown an unpreceden ted change from conventional methods to modernised methodology. With help of advancements in civil engineering construction, solutions, and applications, the shift towards advanced technology and awareness towards eco-friendly products have created a new perspective and acceptance amongst the end-users. The constant rise in demand for progressive ease of construction solutions is shaping the future. Steel has been an integral part for all types of constructions for decades now. Its uniqueness lies in the fact that it reinforces the concrete which protects the construction structure from easy wear and tear that can occur from rust or any natural calamity like an earthquake. Reinforced concrete is the number one medium of construction. It is important to have good quality concrete and reinforcing bar (rebar). It is equally important to have competent bond between rebar and concrete. Reinforced Concrete Construction which is the backbone to any infrastructural project depends for its performance on its prime elements namely Concrete and Reinforcement. Just as mechanization of concrete production namely Mix design, Auto batching plants, Ready Mix technology and automated casting techniques have raised the standards and strengths of concrete to remarkable levels, the same is essential for reinforcement. Usage of Welded Wire Fabric (WWF) is the easy and correct solution for achieving the requirements of quality, reliability, speed and efficiency is a prefabricated reinforcement consisting of a series of parallel longitudinal wires with accurate spacing welded to cross wires at the required spacing. 2 Using welded-wire reinforcement as an alternative to traditional mild steel reinforcing bars has many advantages. Weld Mesh is manufactured in square or rectangular mesh from steel wire, spot welded at each intersection. This is one of the most versatile of industrial wire products and has innumerable applications throughout all types of industry. It is generally manufactured in mild galvanized and stainless steel in different width, size and gauge. Weld Mesh is also used as rebar in reinforced concrete, graded sloped floor, false ceilings, poultry, warehouses for creating divisions, shelfs, mines, gardening, machine protection and other decorations etc

MATERIALS

Generic weld mesh materials are Mild steel, SS 304, SS 316 and galvanised for corrosion resistance. The reinforcing steel wires or bars which are used to reinforce concrete and masonry structures, enabling these to retain their tensile strength through changes in temperature, weather etc. Weld wire mesh has higher yield strength and is produced under higher quality control standards. Cold reduced wires which are plain, ribbed and indented surface configurations steel wire as shown in Fig.1 and Fig.2 with strength grades 500 N / mm ^{2} and 550N / mm ^{2}, used for the manufacture of wire mesh for reinforcement of concrete. Mesh is made as per IS 432-2 grade steel with low impurities and for better welding. These wires are cold reduced from wire rods by passing them through dies / rollers which provide ribs / indentations in the process. Cold reduced wires have less weak areas and provides for better bonding with concrete as can be provided with ribs / indentations. Also, due to uniform microstructure of cold reduced wires, issues of weak welded joints are also reduced in these wires.

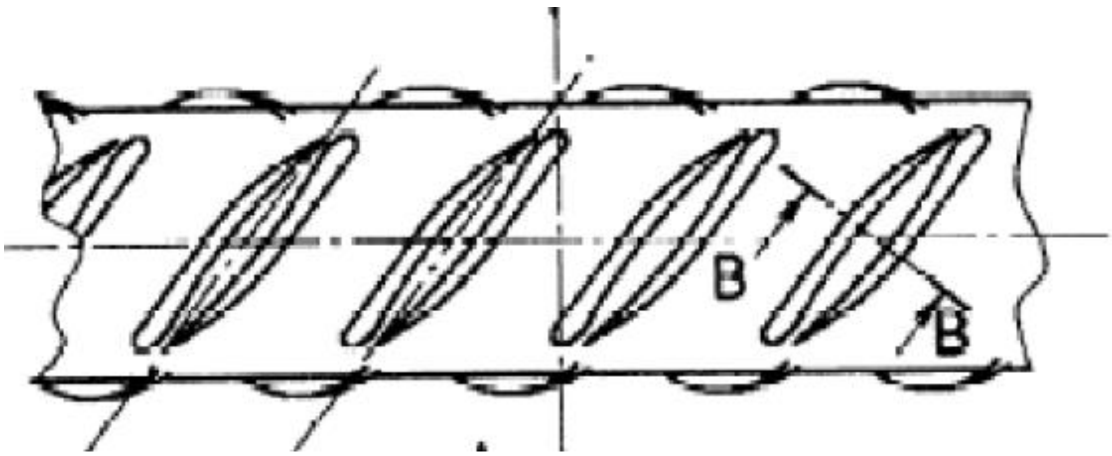


Fig.1: Ribbed Wires or Bars with Three Rows

The wires are covered in IS 432 (Pt 2) Specification for mild and medium tensile steel bars and hard-drawn steel wire for concrete reinforcement. While hot rolled steel wires manufactured through controlled on-line cooling process are covered in IS 1786: High strength deformed steel bars and wires for concrete reinforcement. Further, use of these wires results in steel saving due to increased yield strength of cold reduced wires than hard-drawn plain wires and that of hot-rolled steel wires.

Torkari steel (cold twisted deformed) is mostly used as reinforcement bar (rebar) for the concrete in the construction. The steel contains higher strength (50 and 55 grade) and economic advantages over the predecessors TOR- 40 (40 grade steel). Due to higher strength, it is cost effective. CTD bars however suffered from one disability as it became harder than mild steel during twisting operation and its ductility property reduced. Elongation at breaking point of CTD bars reduced to 14 % as compared to 24 % of Mild steel. Many times, cracks appeared on outer surface of CTD bars while making hooks. It was considered not very suitable to face reversal of stresses an in case of machine foundation or high-rise structures subjected to earthquake or strong wind. Thermo Mechanically Treated (TMT) bar, also called as Reinforcing Bar or Rebar is a high-strength reinforcement bar with a tough outer core and soft inner core made as per IS 1786. TMT steel bars are a new generation of steel bars for concrete reinforcement which is very widely used in present day construction work. Earlier CTD bars i.e cold twisted deformed bars were being used. Prior to that M.S or mild steel bars were in use for R.C.C (reinforced cement concrete) construction works. Rebar is usually made from high-carbon tempered steel and it may be tied together in cross patterns for further reinforcement, and is cast with a ridged surface to aid in adherence to the concrete. 4 The fabric is formed by spacing the main and the cross wires, which shall be fixed at their pointy of intersection by electric welding, so as to be sufficiently stable to withstand normal handling in transport and during concreting, without displacement beyond the limits specified. Fabricated and finished mesh fabricated and finished will assure accurate spacing and alignment of all members of the finished fabric to give substantial square or rectangular openings.

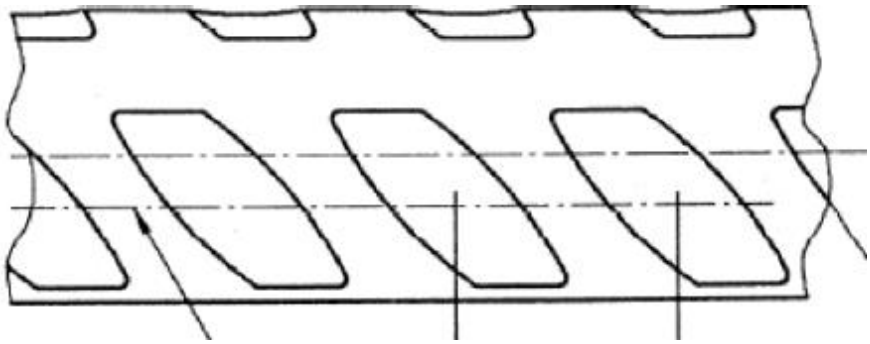


Fig.2: Intended Wires or Bars with Three Rows

STANDARDS & MANUFACTURING

Depending upon design the reinforcement wires / bars may be Cold Drawn Plain Wires, Cold Rolled Ribbed / Deformed Wires or Hot Rolled TMT Bars. Major manufacturers are processing cold drawn plain Wires and cold rolled ribbed / deformed Wires and limited manufacturers are processed with TMT rebars. These require initial Raw material MS Wire Rods of SAE-1008 / 1010 / 1015 or 1018 grades (with %C between 0.8 to 0.18%) . Prime quality Wire Rods are sourced as per standards details shown in table 1.

Welding of the mesh happens on a Multi-Spot-Welding Line comprising of the Long & Cross Wire Pitch Control & Transport Mechanisms and the Multiple Resistance Welding Guns. Spot Welding is fusing (no foreign filler metal) of the Cross Wire into the Long Wire between Copper Electrodes by Passing Heavy Current at Low Voltage (Approx. 11000 Amps for 5 to 12 mm diameter welding at about 6- 10 Volts) under Heavy Force (Approx. 8kN) for a short duration (Approx. 20 cycles or 0.4 sec). A typical machine is shown in Fig.3.

Table 1: Relevant Standards Used for Weld Wire Mesh Fabric

Specification	Title	Parameters	Value
IS:1566 & IS:432 Pt.2	Hard-drawn Steel Wire Fabric for Concrete Reinforcement & Hard-drawn steel wire for concrete reinforcement: Part 2	UTS	570 MPa Min.
		Yield 0.2% Proof Strength	480 MPa Min.
		Elongation on 8 Times Dia GL	7.5% Min
		Weld Shear Strength	Min 25% of UTS
BS:4483 & BS:4482	Steel fabric for the reinforcement of concrete & Steel wire for the reinforcement of concrete products	UTS	1.05 times Yield Strength
		Yield 0.2% Proof Strength	500 MPa Min.
		Total Elongation at Peak force on 5D GL	2.5% Min
		Weld Shear Strength	Min 25% of Yield Strength of Thicker Dia
ASTM A185 & A82	Steel Welded Wire Fabric Plain for Reinforcement & Steel Wire, Plain for Concrete Reinforcement - Grade 60 & Grade 80 (80000 Psi)	UTS Grade 80 / Grade 60	620 MPa Min / 515 MPa
		Yield 0.35% Proof Strength	550MPa Min / 450 MPa
		Reduction in Area (after Failure)	30% Min
		Weld Shear Strength	241 MPa in Thicker Dia

Fig.3: Automatic Spot Welding Machine for WWF

Pitch Control of Long Wires is generally set fixed for one batch and needs resetting for each batch of Long Wire pitch sets. Some New Installations have Robotic type Moving Electrode guns controlled by PLC for quick change over of Long Wire Pitch sets. Pitch Control of Cross Wires is by a Setting Adjustable Mechanical Cam Motion or By Online Variable Stepper / Servo Motor driven Motion.

QUALITY ISSUES

Recommended welding is Semi or automatic multi- spot-welding machines for Resistance welds with no foreign filler metal. The Spot-welding technology works well and reliably with Steels of low carbon (< 0.15 % C) and of homogeneous Cross-section as in Cold Rolled Ribbed Bars / Cold Drawn Plain Wires. The weld mesh to qualify the shear strength as per IS 4948 for projection welding with the increasing use of advanced high- strength steels, and the emerging trend toward the adoption of simulation resistance welding to reduce weld verification testing and preproduction 6 scrap and labour. The projection welding, it is not possible to weld without expulsion & the problem is controlling the amount of expulsion and obtaining the required strength. Standardized procedures are needed for determining the weldability of materials for cross wire welding. Hot Rolled TMT bars have higher carbon (typically 0.18- 0.30 % C) and heterogeneous Cross- section (outer hard Martensite RIM, Transition zone & Inner soft Ferrite / Pearlite Core zone including a spiral fin). Spot welding of TMT bars leads to unreliable and inconsistent welds if not done properly. Unreliable welds which may snap in handling are more dangerous than NO WELDS as they lead to loss of Crosssection and design strength.

USES OF WELD MESH

Reinforced weld mesh is used in construction, having applications in floor slabs of warehouses as well as residential housing projects with the inclusion in shear walls, to reinforce roadways, walkways and floors. The major advantage of usage of weldmesh is reducing the risk of cracks and deterioration of concrete without the added expense of rebar. Mesh usage can cut down rebar placement times in Slabs & Walls from days to hours. Its use also results in fewer labour costs associated with construction. Welded wire mesh in a variety of industries, from agriculture and horticulture to transportation, mining, and construction.

Reinforcement Bars Diameter like 6, 7, 8, 9, 10 mm of welded wire mesh can make a good internal framework for reinforced concrete structures. Usage of weld mesh provides substantially increased tensile strength to a material that is otherwise quite vulnerable to cracking under the forces of vibration, twisting, and warping. Also these are used in Road beds, Walkway beds, Concrete foundations, Industrial strength floors and ceilings, Concrete walls, Factory conveyor belts etc. Fig.4 shows weld mesh fabric.

The strength and flexibility of welded fabric is crucial in construction and reinforcement of arches and domes, thereby preventing the emergence of cracks in the structures. With this construction of arches and domes is easy otherwise it would have been very cumbersome. Prefab walls are factory assembled based on design requirement and can be installed easily.

Fig.4: Typical Weld Mesh Fabric Ready for Use

REINFORCED CONCRETE PAVEMENT

Continuously Reinforced Concrete Pavement (CRCP) is a type of rigid pavement, employed in highway construction owing to its host of benefits shown in Fig.5 . Materials used to include concrete and steel (steel bar, wire fabric) with concrete, dense and low permeability concrete mix is required with a maximum water content ratio of 0.42 to 0.45. Similarly, with steel, which is used in steel bar and fabricated wire mesh forms, specific grades need to be selected based on strength properties. In all, based on the application and end result, the technical specifications for the materials need to be fixed accordingly.

Fig.5: Continuously Reinforced Concrete Pavement

The pavement forms transverse cracks at close intervals due to the continuous reinforcement, which itself results from the change in concrete volume. Ideally, a thoroughly designed CRCP that's built using superior quality materials can keep the mentioned cracks tightly closed, thereby minimizing water penetration and other similar problems. There are fewer joints and tightly closed transverse cracks, water penetration can be reduced as well. These roads can handle heavier truck loading and volume. While its initial cost is high, it has a longer life cycle, which keeps the overall cost in the long run low.

GRATING

A perfect combination of strength, low cost, and ease of installation makes welded wire mesh a popular choice for grating roads providing ventilation for subway systems and for covering street side drains as shown in Fig.6.

Fig.6: WWF Used in Grating Beside Road

FENCING

Those looking for a relatively cheap security solution that's tougher than chain link and still allows visibility will often turn to welded wire mesh. Application sites range from lower-security prisons and military installations to private offices and residences. It may even be placed within factories and other industrial buildings as a guard material surrounding heavy machinery as shown in Fig.7.

DECORATIVE PURPOSES

Welded wire mesh is available in multiple colors and coatings, and can in fact make for a visually appealing framework for trellises, flowerbed enclosures, and birdcages among others. Some find it a perfect fit for elevating plants above the ground, or for shelving in garden sheds, closets, and even retail stores.

Fig.7: WWF Used as Security Fencing Purposes

ADVANTAGES OF WWF

The usage of proper grade of weld mesh in construction will fetch many advantages. These are improved site efficiency & productivity with reduced reliance on manpower on-site. The chance of improper bending of bars is reduced since bending machines bend the mat as a single unit. Provides the exact size of reinforcement where needed through variable bar size and spacing. The other benefits are as below:

Cost Reduction

Eliminate labour costs on cutting, binding and placing rebars
Save cost of binding wire
Reduce inventory costs and working capital

Design Optimised

Use any diameter from 2-12mm unlike rebars
Optimized designs for reinforcement requirements
Reduce overall steel requirement

Smart Execution

Easy tracking to minimize pilferage
Easy inspection for structural consultants
Perfect spacing through mechanized process
Faster Construction and Reduction in Labour

Save Time

A prefabricated solution that reduces slab to slab casting time
Ready-to-use materials delivered at site
Valuable labour hours saved

FATIGUE PERFORMANCE

Weld wire mesh has been the standard reinforcement for bridge I-girders and inverted-tee girders. Structural members fail due to fatigue when cracking develops under repetitive loads that are less than their static load capacity. The process starts with the initiation of cracking, followed by propagation of cracking, in which micro-cracking gradually takes place in the concrete or cracking grows in a steel element. Slow crack growth is followed by a brief period of quick growth, which leads to the third stage: fracture. WWR is more desirable than deformed bars for fatigue applications because after first wire fracture, alternate load paths are available through the fabric and multiple fractures have to occur before the performance of the concrete panel is severely affected.

CORROSION ISSUE

The pH of hardened concrete is alkaline and is generally in the range of 12.6 to 13.5. Carbonation will result in reduction of pH of concrete resulting in rupture of passivating layer around the embedded reinforcement which otherwise protects it from corrosion. Weld mesh wire / bars used are cold drawn, hot rolled, cold twisted and quenched & tempered used for construction. The microstructures are different from pearlite ferrite (cold drawn) to tempered martensite (QST Rebars) and steels are having residual stresses (Tor). It is expected that there will be variation in polarization behavior and corrosion rates of all these steel with different microstructures. It is reported that corrosion rate increases in the following sequence: pearlitic to martensitic to tempered martensitic steels when pH value drops to a greater extend. Though the corrosion starts and continues with the creation of galvanic cell between cathodic carbide and anodic ferrite phases, corrosion mechanism differs for the steels with microstructures, attributing to the size, shape, and distribution of galvanic couple.

CONCLUSION

Welded wire fabric is used as reinforcement to add to the strength of slabs and ensure a stronger, more stable overall construction. There are a variety of advantages associated with the use of welded wire fabric or reinforcing bars in a slab. This article has looked at some applications of weld wire mesh using cross wire welding and are also made from hot rolled steel, cold drawn and TMT bars instead of the standard International Specs accepted practice of using cold rolled ribbed bars, cold drawn plain wires. Many designers are reluctant to use weld wire mesh as an alternative to mild steel reinforcing bars due to the unavailability of fatigue design guidance. Corrosion studies are also import to evaluate the durability of concrete with respect of steel types having different microstructures. Both CTD and TMT bars of high strength steel have another shortcoming to contend with the effect of stresses on corrosion is reflected more distinctly in the mechanical characteristics of the reinforcement, specially of high-strength steels with low ductility.

ACKNOWLEDGEMENT

Author is thankful to Weld Mesh Manufacturers Association (WMA) for providing an opportunity to work with the weld mesh wire fabric product usage in construction segment. WMA has been at the forefront in developing products that are equipped with best-in-class features pertaining to durability, cost-effectiveness without any compromise on the quality.

REFERENCES

1. . ISO 10544 - 1992, “Cold-reduced Steel Wire for the Reinforcement of Concrete and the Manufacture of Welded Fabric”, The International Organization for Standardization, Geneva, Switzerland.
2. .IS 4948 – 2002, “Welded Steel Wire Fabric for General Use”, Bureau of Indian Standards, New Delhi, India.
3. .IS 1566 – 1982, “Hard Drawn Steel Wire Fabric for Concrete Reinforcement”, Bureau of Indian Standards, New Delhi, India.
4. . IS 280 - 2006. “Mild Steel Wire for General Engineering Purpose”, Bureau of Indian Standards, New Delhi, India.
5. . IS 432 (Part 2) – 1982, “Mild Steel and Medium Tensile Steel Bars and Hard Drawn Steel Wire for Concrete Reinforcement”, Bureau of Indian Standards, New Delhi, India.
6. . IS 1786 – 2008, “High Strength Deformed Steel Bars and Wires for Concrete Reinforcement”, Bureau of Indian Standards, New Delhi, India.
7. .Product Brochures of Tata Steel

Ltd.8. Product Brochures of JSPL

9. .Product Brochures of S K Wire Mesh
10. .Product Brochures of Western India Wire Industries
11. .Product Brochures of Eastern Wire mesh
12. . Wilast Amorn, “Fatigue of Deformed Welded-Wire Reinforcement”, PCI Journal, Vol.Jan-Feb, 2007.
13. . P K Katiyar and K. Mondal, “Comparative Corrosion Behavior of Microstructures Made from a High Carbon Steel”, Metallurgical and Materials Transaction, Vol. 50A, Page No. 1489, March, 2019.
14. . Ilona Iatcheva, “Modelling of Electric and Heat Processes in Spot Resistance Welding of Cross-wire Steel Bars”, Open Physics, 2018, Vol.16, Pages 1–8.
15. . A Kar, “Rebars for Durable Concrete Construction: Points to Ponder Design of Cities and Building”, Intech Open, London, January 2021.
16. . A Nielsen, “Cross-wire Welding Analyzed By Experiments And Simulations”, Science Direct, Journal of Advanced Joining Processes, Vol.3, 2021.

INNOVATIVE USAGE OF STEEL HOLLOW SECTIONS IN STEEL-BASED CONSTRUCTION

Ravi Kumar

Tata Structura Team, Tata Steel Tubes (M&S)
Tata Steel Limited, Jamshedpur

ABSTRACT

Steel hollow sections are proving to be the most versatile and efficient form of structural steel for construction and mechanical applications. Many of the iconic and most impressive structures in the world would not have been possible without use of hollow sections.

Tata Structura was launched in 2005 and is currently the leading steel hollow section brand in project construction in India. Tata Structura has been used in more than 40 airports, 20 stadiums, 7 metro projects and many more iconic projects across India. Tata Structura YST 355 was launched in 2015 and was the first brand to launch YST 355 grade steel hollow section in India.

In this report, we are covering two topics regarding innovative usage of steel hollow section in steel-based construction as part of our initiatives from Tata Structura:

a) Concrete filled tubes (CFT)

b) Concept of Diagrid structures

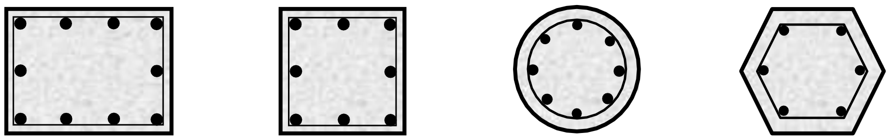
INTRODUCTION

Concrete filled steel tubular members, comprising a hollow steel tube in-filled with concrete, have been used in many structural applications, especially for columns in high rise buildings and bridge piers. The other applications include structural uses in infrastructure, industrial buildings, offshore oil and gas installations and retaining or supporting structures.

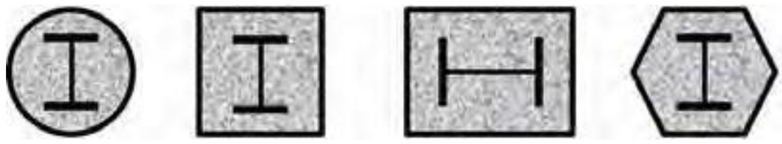
Concrete-Filled Steel Tubes (CFTs) are composite members consisting of a steel tube in-filled with concrete with or without reinforcement (Fig. 1). In current international practice, CFT columns are used in the primary lateral resistance systems of both braced and unbraced building structures. There exist applications in Japan and Europe where CFTs are also used as bridge piers. Moreover, CFTs may be utilized for retrofitting purposes for strengthening concrete columns in earthquake zones.

The concrete core adds compressive strength and stiffness to the tubular column which reduces possible for inward local buckling. The steel tube acts as longitudinal and lateral reinforcement for the concrete core helping it to resist bending moment, shear force and twisting moment which provides confinement for the concrete. Since the benefit of these composite action of two such materials, CFT columns provide better seismic resistant structural properties such as rise in ductility, increase in strength and enormous energy absorption capacity.

Concrete filled tubes without reinforcement



Concrete filled tube with reinforcement



Concrete filled tube with an encased steel section inside

Fig.1: Concrete Filled Tubes with or without Reinforcement

ADVANTAGES OF CONCRETE-FILLED STEEL TUBES

The CFT structural member has a number of distinct advantages over an equivalent steel, reinforced concrete, or steel-reinforced concrete member.

1. . The Concrete Filled Steel Tubular (CFST) column offers numerous structural benefits, including high strength, fire resistance and higher energy absorption.

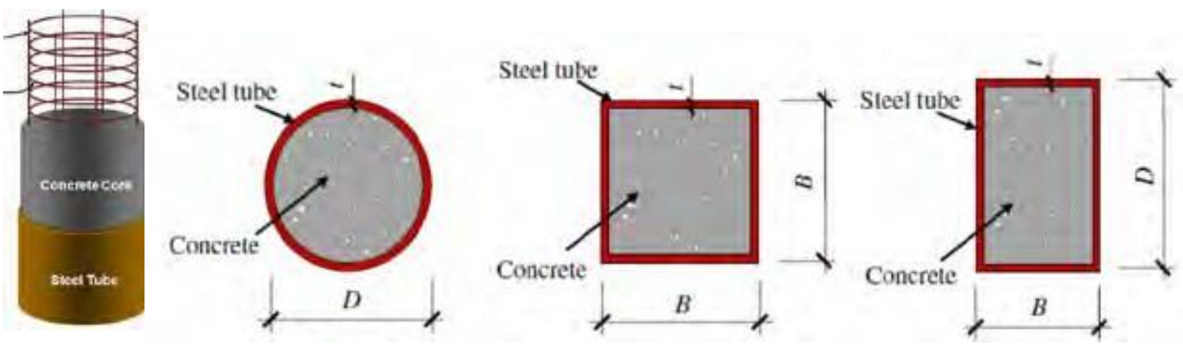


Fig.2: Concrete Filled Steel Tubular Column

2. . The orientation of the steel and concrete in the cross section optimizes the strength and stiffness of the section. The steel lies at the outer perimeter where it performs most effectively in tension and in resisting bending moment.

3. Also, the stiffness of the CFT is greatly enhanced because the steel, which has a much greater modulus of elasticity than the concrete, is situated farthest from the centroid, where it makes the greatest contribution to the moment of inertia.
4. The concrete forms an ideal core to withstand the compressive loading in typical applications, and it delays and often prevents local buckling of the steel, particularly in rectangular CFTs.
5. Additionally, it has been shown that the steel tube confines the concrete core, which increases the compressive strength for circular CFTs, and the ductility for rectangular CFTs. Therefore, it is most advantageous to use CFTs for the columns subjected to the large compressive loading.
6. In contrast to reinforced concrete columns with transverse reinforcement, the steel tube also prevents spalling of the concrete and minimizes congestion of reinforcement in the connection region, particularly for seismic design.

Recent applications have also introduced the use of high strength concrete combined with high strength thin-walled steel tubes with much success. When high strength concrete and thin-walled steel tubes are used together, the more brittle nature of high strength concrete is partially mitigated by the confinement from the steel tube, and local buckling of the thin steel tube is delayed by the support offered by the concrete. Progress in concrete technology has made it possible to utilize concrete strengths over 100 MPa in CFT beam-columns.

In addition to the above advantages, we can see several other economic benefits branching from the use of CFTs.

The tube serves as formwork in construction, which decreases labor and material costs. In moderate- to high-rise construction, the building can ascend more quickly than a comparable reinforced concrete structure since the steelwork can precede the concrete by several stories. The cost of the member itself is much less than steel and roughly equivalent to reinforced concrete on a strength per dollar basis for low to medium strength concrete.

When compared to steel moment resisting frames, in unbraced CFT frames, the amount of savings in steel tends to grow as the number stories increases.

On the other hand, relatively simple beam-to-column connection details can be utilized for rectangular CFT members. This also results in savings for the total cost of the structure and facilitates the design process.

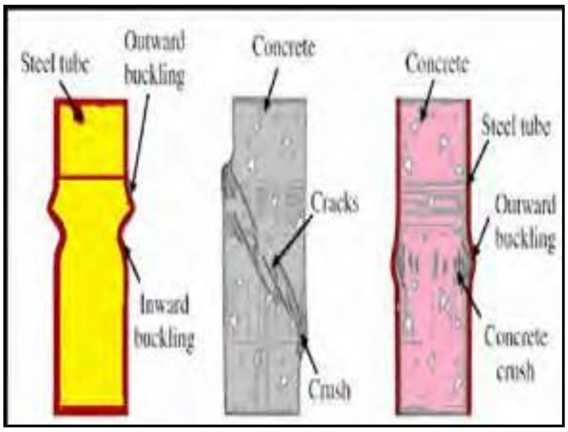
In addition, the steel tube and concrete act together to provide natural reinforcement for the panel zone, which reduces the material and labor costs of the connections. With the use of high-strength concrete, CFTs are stronger than conventional reinforced concrete columns for equivalent cross-sectional area.

In high-strength applications, smaller column sizes may be used, increasing the amount of usable floor space in office buildings. The smaller and lighter framework places less of a load on the foundation, cutting costs again. These advantages have secured an expanding role for this versatile structural element in modern construction.

STRUCTURAL BENEFITS OF CONCRETE-FILLED STEEL TUBES

The concrete core adds stiffness and compressive strength (Fig. 3) to the tubular column and reduces the potential for inward local buckling. Conversely, the steel tube acts as longitudinal and lateral reinforcement for the concrete core helping it to resist tension, bending moment and shear and providing confinement for the concrete.

Due to the benefit of composite action of the two materials, the CFT columns provide excellent seismic event resistant structural properties such as high strength, high ductility and large energy absorption capacity



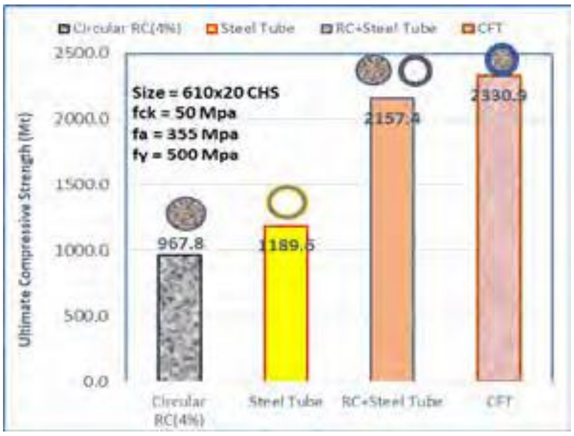


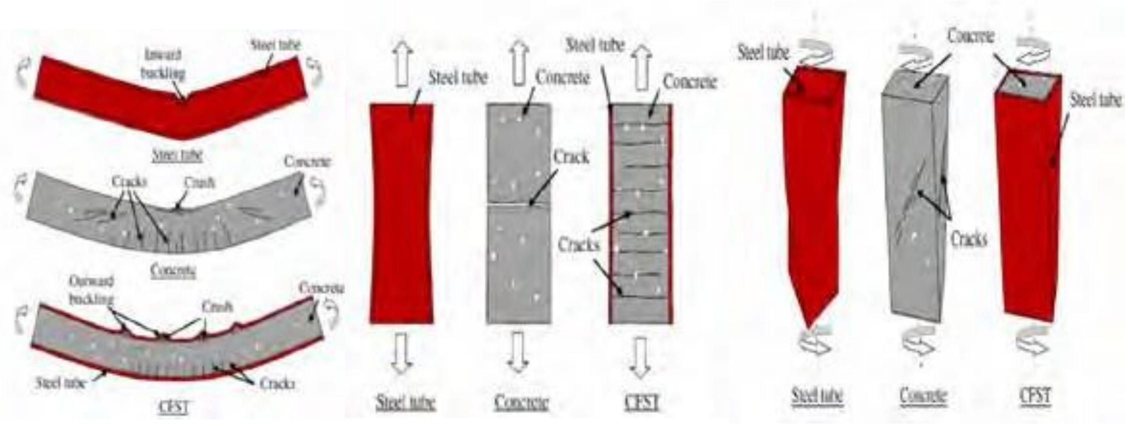
Fig.3: Axial Compressive Strength for Different Stub Columns

The compressive strength of the CFT column is seemed to be higher than the arithmetic sum of the strengths of RC column (4% reinforcement) and steel tube without any fill, due to the effect of confinement of concrete by the outer skin of steel tube. The effect of confinement is more in case of a circular section in-filled with concrete than any shaped section filled with concrete. The structural benefits of CFT in case of other structural elements can be seen below:

DESIGN PERFORMANCE ANALYSIS OF CFT COLUMNS

a) Comparative analysis of Columns with or without fill of concrete of different grades is shown in Fig. 4. The compressive strength of columns increases by almost twice in case of large dia. HS filled with higher grade of concrete like M50 or M60.

b) Comparative analysis of RCC Columns versus CFT columns with same cross- sectional areas is shown in Fig.5 and Fig.6.



Hollow Section	Compression Capacity (Mt)		
	Without Fill	Concrete Grade	With Fill
CHS 610x20	1189.6	M20	1636
		M30	1798
		M40	1958
		M50	2119
SHS 500x500x20	1221.6	M20	1621
		M30	1755
		M40	1887
		M50	2020

- ❑ **EUROCODE 4**
- ❑ **ANSI/AISC 360-16**
- ❑ **GB 51249-2017**
- ❑ **ACI 318**

✓ **IS 11384 (Under Draft)**

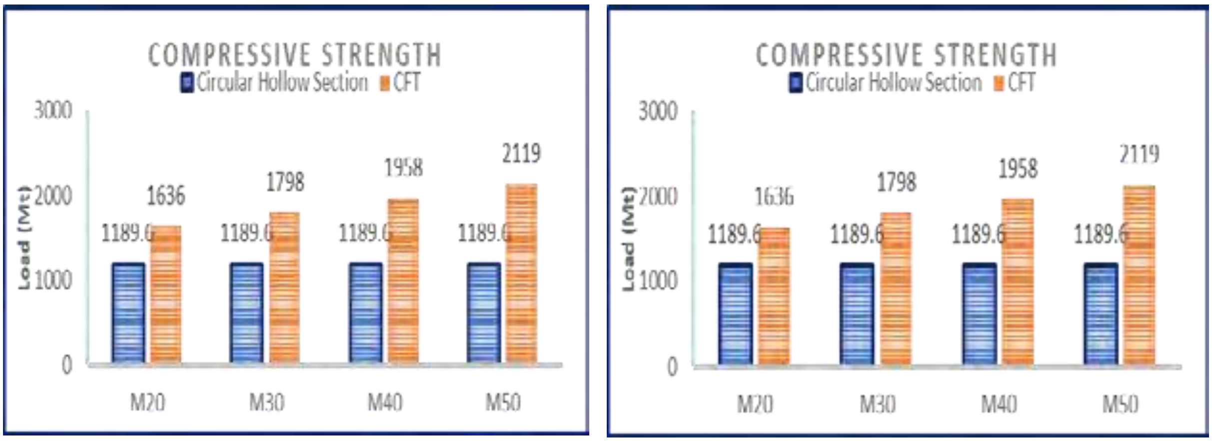


Fig.4: Advantages of CFT in Different Structural Elements

	Compression Capacity (Mt)		
	Concrete Grade	CFT	Circular RC(4%)
CHS 600x20	M20	1635.8	625.8
	M30	1798	739.8
	M40	1958.6	853.8
	M50	2119	967.8

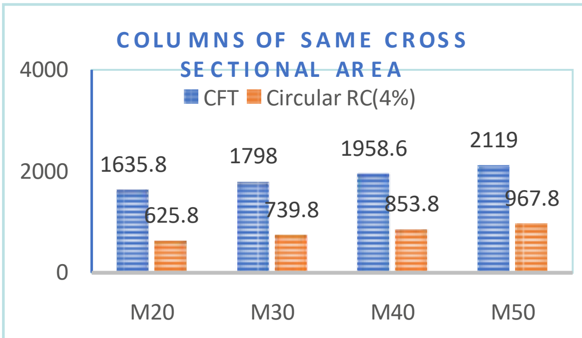


Fig.5: Circular RC Columns (4% reinforcencement) Versus Circular CFT Columns

	Compression Capacity (Mt)		
RHS 500x500x20	Grade of concrete	CFT	Rectangular RC(4%)
	M20	1621	527.0
	M30	1754.5	623.0
	M40	1887.3	719.0
	M50	2020	815.0

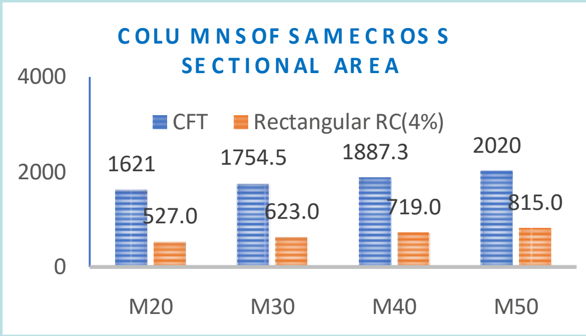


Fig.6: Square RC columns (4% reinforcencement) Versus square CFT Columns

ADVANTAGES OF CFT IN MULTI-STOREY BUILDINGS

- Delayed local buckling & Strength enhancement due to confining effect
- Reduction in drying and creep shrinkage
- Saving of manpower, constructional cost, and time
- Increased usable floor area due to reduced column size
- Improvement in fire resistance performance
- Safer and more reliable in seismic region
- Reduction in overall Construction Time by 1/3rd.
- Reduction In steel Consumption by 15 -20%
- Better fire resistance of up to 60 minutes
- Reduction in Space of the RCC Column Size by 30 - 40%, more usable plinth area
- Overall Cost Saving in the tune of 10 -20%

KEY CFT PROJECTS IN INDIA

L&T Business Towers and Business Park, Mumbai

Box section used:

1200 mt of 1100x800x16
Primary application for columns

Technology Adopted:

Concrete filled tubes
Usage of CFT columns with no reinforcement enabled the construction of 3 floors simultaneously

Total construction time = 27 months

Slab cycle time was reduced to 7 days and overall time savings of 3.6 months was achieved

Project was completed successfully by L&T Reality

Parameters	RC	Steel	CFT
Section Size	Large	Small	Small
Seismic Behaviour	Fair	Excellent	Excellent
Fire resistance	Excellent	Fair	Good
Construction ability	Not good	Excellent	Excellent
Anti-corrosion	Good	Good	Good
Long term behaviour	Not Good	Good	Good


Canton Tower, China


Wangchang East River Bridge, China


Queensberry House, London


Ganhaizi Bridge, China


Electric Poles, China


SEG Plaza, Shenzhen, China


Fleet Palace House, London


Moorgate Exchange, London

Fig.7: Some Major CFT Projects Outside India

LIMITATIONS OF CONCRETE-FILLED STEEL TUBES

1. . A primary deterrent to widespread use of CFTs is the limited knowledge regarding their behavior.
2. . A number of factors complicate the analysis and design of concrete- filled steel tubes. A CFT member contains two materials with different stress- strain curves and distinctly different behavior. The interaction of the two materials poses a difficult problem in the determination of combined properties such as moment of inertia and modulus of elasticity.
3. . The failure mechanism depends largely on the shape, length, diameter, steel tube thickness, and concrete and steel strengths. Parameters such as bond, concrete confinement, residual stresses, creep, shrinkage, and type of loading also have an effect on the CFT's behavior.
4. . Axially loaded columns and, in more recent years, CFT beam-columns and connections, have been studied worldwide and to some extent many of the issues have been reconciled for these types of members. However, researchers are still studying topics such as the effect of bond, confinement, local buckling, scale effect, and fire on CFT member strength, load transfer mechanisms and economical detailing strategies at beam-to-CFT column connections, and categorization of response in CFTs and their connections at all levels of loading so as to facilitate the development of performance-based seismic design provisions.
5. . It should also be noted that, despite a recent increase in the number of full-scale experiments, the majority of the tests to date have been

conducted on relatively small specimens, often 6 inches in diameter or smaller. This is due to the load limits of the testing apparatus and the need to run the tests economically. Whether these results can be accurately extrapolated to the typically larger columns used in practice remains a pertinent and debatable question.

DIAGRID STRUCTURES

The basic idea for developing a diagridsystem is to eliminate vertical columns. Vertical columnscarry only gravity loads and incapable of providing lateral stability. A tall building should resist both gravity loads and lateral loads (due to wind, earthquake, etc.). Diagrid system provides this facility. This structural system resists both gravity and lateral loads, by the action of axial forces in an effective manner. Diagrid is an exterior structural system consisting of only inclined columns on the façade. The Concept of diagrid evolved from the braced tubular structure systems. The skin of the building is a truss network of hollow sections with nodes that are welded during assembly. Steel floor beams are spanned between the peripheral nodes and central ring beam and these floor beams support the composite floor slabs. The core that houses the services has columns of reinforced concrete with optimal and varying thickness of structural steel usage.

- ❑ Absence of vertical members in the perimeter of diagrid system
- ❑ Diagonals acting as both inclined columns and bracing elements
- ❑ Shear and overturning moment developed are resisted by axial action of diagonal members

Advantages of Diagrid System

- Maximum exploitation of the structural material
- Aesthetically dominant and expressive
- 20% reduction in steel as compared to braced frame
- Good day lighting due to dearth of interior columns
- Sustainability, Energy efficiency & Low environmental cost

Structural Benefits in Dia-grid Framework

- Good response to intense lateral pressure in tall commercial buildings Useful for both gravity and lateral loads for large span and high- rise buildings

Key CFT Projects in India

a) I-Lab Building, Hyderabad (Designed by Construction Catalyser)

This unique oval dome shaped (55m x 23m x 21m) design is demonstrated by an exclusive dia-grid concept used effectively to provide good visual lightness and barrier-free usable office spaces inside. The self-supporting structure with minimal vertical supports imparts the building an innovative look and reduces low life cycle costs further. This five-storied prefabricated light weight structure took eight months for construction.

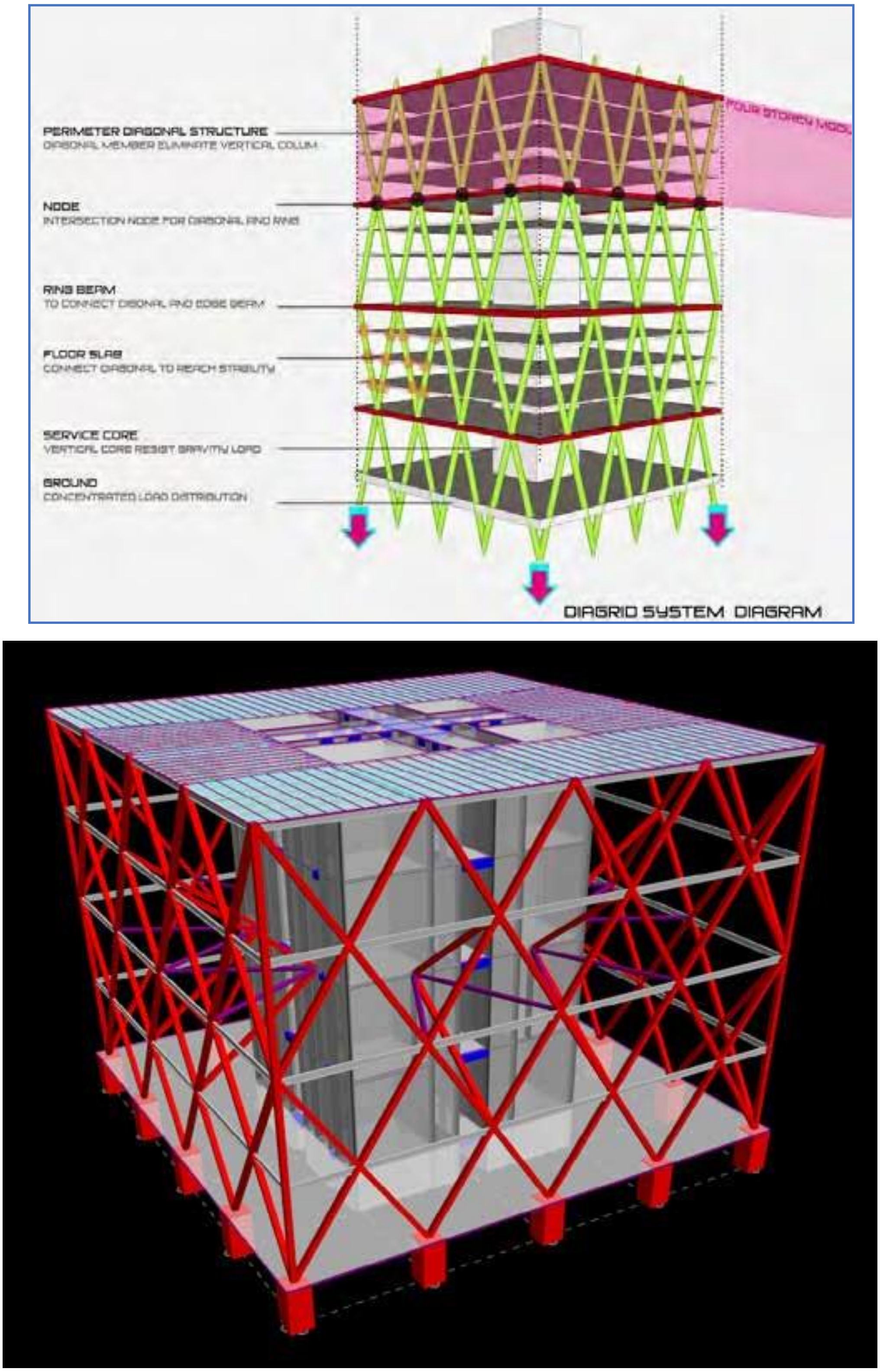
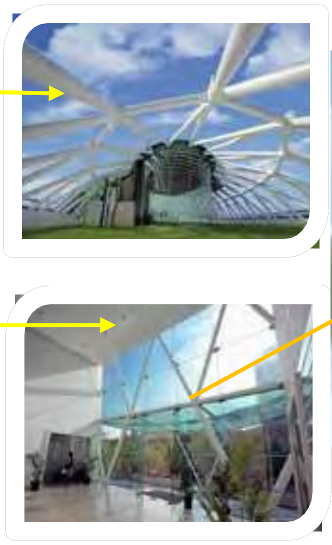


Fig.8: Modelling of a Diagrid Structure

The i-Lab building has become an icon in its class – and it owes this status to the unique approach towards the merit of the structure and architectural manifestation.

I-Lab building, Hyderabad



Roof & Façade view

Axial Connections

b) Elevate Interior building, Bangalore (Designed by Opus Architect, Bangalore)

LIMITATIONS / CONSTRAINTS IN THE DIAGRID FRAMEWORK KNOW-HOW:

- Unavailability of skilled workers
- Limited exploration in the field of Diagrid construction techniques
- Difficulty in erection of Nodes
- Complex engineering in design and fabrication of Joints
- Dependency of number of storeys on the primary module height

CONCLUSION

Structural Hollow Sections are the most efficient of all structural steel sections in resisting compression. Tata Structura hollow sections have a high strength to weight ratio and produce slender attractive lines that make them a natural choice for building structures. These hollow sections can achieve a constant external dimension for all weights of a given size, which enables them to achieve standardisation of architectural and structural details throughout the full height of the building if required. Concrete-filled steel tube (CFT) columns combine the advantages of ductility, generally associated with steel structures, with the stiffness of a concrete structural system. While many advantages exist, the use of CFTs in building construction has been limited, in part, to a lack of construction experience, a lack of understanding of the design provisions and the complexity of connection detailing. The new-age structural material from Tata Steel has opened up a world of possibilities for all these innovative technologies. The presence of higher grade like YST 355 and large dia. sections (up to 600 NB in CHS, 400x 400 in SHS and 400x 200 in RHS) has provided a support to designer to think beyond the expected.

Diagrid - Diagonalised grid structures is one of the emerging innovative concepts to design tall buildings. Diagrid- a word formed by combination of "diagonal" and "grid". Diagrid structures act like free standing cantilevers and resist both, gravity, and lateral loads, by the action of axial forces in an effective manner. It is observed that, in diagrid 33 % less steel is required than conventional building. Also, architecturally diagrid structures give more aesthetic than conventional building. The steel hollow sections from Tata Structura have enabled designers, architects, and engineers to add wings to their imagination. They are now able to explore new ways and experiment more with innovative designs to boost aesthetics, strength, and durability of their creations with the help of Tata Structura hollow sections. With Tata Structura available grade & hollow sections, this innovative structural framework will also get a boost in the emerging trend of construction.

REFERENCES

1. . EN 1992- 1 -1 (2004), "Eurocode 2: Design of concrete structures – Part 1 -1: General Rules and Rules for Buildings", European Committee for Standardization, Brussels.
2. . EN 1993- 1 -8 (2005), "Eurocode 3 - Design of steel structures – Part 1- 8: Design of Joints" European Committee for Standardization, Brussels.
3. . Y C Wang, "Design of Reinforced Concrete Filled, Hot Finished Structural Steel Hollow Sections in Fire", Non-contradictory Complementary Information (NCCI), 2014.

4. . Y C Wang, "Design Guide for Concrete Filled Hot Finished Structural Hollow Section (SHS) Columns",

5. . BC 1 (2012), "Design Guide on Use of Alternative Structural Steel to BS 5950 and Eurocode 3", Building and Construction Authority, Singapore.

6. . BC 4 (2015), "Design Guide for Concrete Filled Tubular Members with High Strength Materials. An Extension of Eurocode 4: Method to C90/105 and S550 Steel", Building and Construction Authority, Singapore.

7. . BC 2 (2008). Design guide of high strength concrete to Singapore standard CP 65. BCA Sustainable Construction Series – 3, BCA Academy, Singapore.

8. . SCI : P 358 , " Joints In Steel Construction: Simple Joints to Eurocode 3", Steel Construction Institute and British Construction Steel Work Association, UK, 2011.

9. . Lin-Hai Han, Wei Li and Reidar Bjorhovde, "Developments and Advanced Applications of Concrete-filled Steel Tubular (CFST) Structures: Members", Journal of Constructional Steel Research Vol.100, Pages 211–228, 2014.

A JOURNEY INTO THE WORLD OF CORROSION

Sohini Mitra

Manager – Engineering Design
Trishul Engineering Solutions Pvt. Ltd.
&
Aniruddha Lahiri

Founder Chairman
Trishul Engineering Solutions Pvt. Ltd.

INTRODUCTION

The word corrode is derived from the Latin word "corrodere" which means "to gnaw to pieces" Corrosion can be defined as a chemical or electrochemical reaction between a material, usually a metal/alloy, and its environment that produces a deterioration of the material and its properties. Often corrosion results in the damage to the usage of the material considered inspite of the best design, fabrication and maintenance. In this article, a brief has been provided on the chemistry of corrosion, factors affecting the rate of corrosion, major types of corrosion encountered, effects of corrosion on the steel structure and major accidents reported, corrosion prevention and management. A synopsis on the case study of corrosion in a spray drying tower of a detergent manufacturing plant is also included.

CHEMISTRY OF CORROSION

Corrosion is an electrochemical process, which in the presence of moist air, degrades and eventually leads to loss of surface material. However this is a time dependent process, i.e. the longer a component is exposed to corrosive environment, the more it corrodes. High humidity coupled with the presence corrosive chemicals in dust or vapor form, high ambient temperature and inadequate air circulation are some of the main reasons for corrosion.

Structural steel is an alloy made up of mainly iron and a small percentage of carbon; the final product after this degradation is called rust. This reaction is often called an oxidation reaction since there is the formation of respective oxides at the end of the process.

Initial attack occurs at anodic areas (Fig. 1) on the surface, where ferrous ions go into solution. Electrons are released from the anode and move through the metallic structure to the adjacent cathodic sites on the surface, where they combine with oxygen and water to form hydroxyl ions. These react with the ferrous ions from the anode to produce ferrous hydroxide, which is further oxidized to produce hydrated ferric oxide (i.e. red rust.) The sum of these reactions can be represented by the following equation:

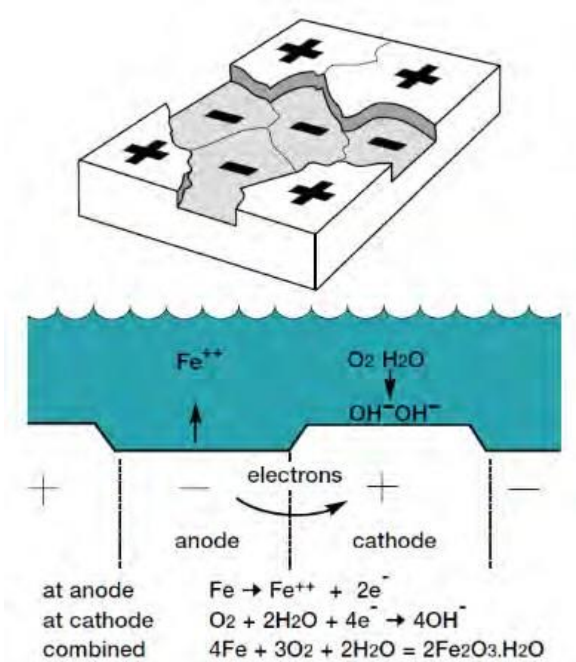


Fig.1: Chemical Reactions of Corrosion Process

Fe	+ $3O_2$	+ $2H_2O$	=	$2Fe_2O_3H_2O$
(Steel)	+ (Oxygen)	+ (Water)	=	Hydrated ferric oxide (Rust)

The corrosion process requires the simultaneous presence of water and oxygen. In the absence of either, corrosion does not occur. The process is facilitated by the presence of dust and chemicals.

FACTORS AFFECTING THE RATE OF CORROSION

The electrolyte is usually water. The flow of electrons is from anode to cathode. As negatively charged electrons leave the anode, positively charged ions of the anode metal are released into the electrolyte. These ions can react with other materials to form corrosion products called "rust". Due to this, the anode is damaged and the cathode is undamaged. Since, there is presence of a metal (steel), electrolyte (moist environment such as water) and current flow through this electrolyte from anode to cathode (galvanic couple), the corrosion process can be compared to a simple "corrosion cell." An oxygen cell is a type of corrosion cell in which oxygen concentrations in the electrolyte determine the anode and cathode locations. Locations where the electrolyte oxygen concentration is low (such as stagnant standing water) are anodic and prone to corrosion. Metals at point of low ion concentration corrode. In some cases, certain bacteria can also affect the rate of corrosion because their metabolic processes can alter the oxygen and metal ion concentrations in the electrolyte.

Among many other factors, corrosion can also be affected by environmental effects which include temperature and humidity. High temperature increases the rate of corrosion. The amount of moisture available is very crucial to the rate of corrosion because water serves as an electrolyte. In regions where water is scarce, corrosion rate is slow compared to regions with above-average precipitation. Exposure is important in assessing corrosion on a single structure. Areas exposed to wind or sun that can dry quickly are less prone to corrosion than sheltered areas where water can remain in contact with the metalwork.

Salt spray from breaking waves and onshore winds significantly accelerates the corrosion of steel structures in marine environments. The ocean salts, which are primarily sodium chloride but include chlorides of other metals such as potassium or magnesium, accumulate on the metal surfaces and accelerate the electrochemical reactions that cause rusting and other forms of corrosion. The combination of salt accumulation on the surface and the high humidity common to many coastal areas significantly accelerates the corrosion rate of steel. The longer a surface remains damp during normal daily fluctuations in humidity, the higher the corrosion rate. Onshore winds carry both salt and moisture inland. Therefore, corrosion rates along shorelines with predominately onshore winds will be higher than those along shorelines with predominately offshore winds.

MAJOR TYPES OF CORROSION

- Uniform Corrosion
- Galvanic or Bimetallic Corrosion
- Crevice Corrosion
- Pitting Corrosion
- Stress Concentration Cracking

Uniform Corrosion

Uniform corrosion is the most common type and is characterized by attacks over the entire surface area of the metal exposed to a corroding agent. This type of corrosion is typically caused by chemical or electrochemical reactions that cause the metal to be consumed while forming oxides or other compounds over large visible areas.

a. Galvanic/Bimetallic Corrosion:

Bimetallic corrosion, also known as galvanic corrosion, is the corrosion that occurs when two dissimilar metals are directly or indirectly in contact with each other. Visually, this type of corrosion is characterized by the accelerated deterioration of one metal, while the other remains less affected.

Bimetallic corrosion is a purely electrochemical reaction driven by the difference in electrode potentials between the two metals. When exposed to an electrolyte, the two metals form a type of cell known as a bimetallic couple, where one metal acts as the anode and the other as the cathode. The movement of electrons from the anode to the cathode initiates an oxidation reaction at the anode that causes it to be dissolved, i.e., corrode.

Metals that are further from each other in the "Galvanic Series" have the highest rate of corrosion when combined. By knowing the relationships of the metals in the series, galvanic compatibility can be determined, preventing the possible harmful effects of galvanic corrosion.

Galvanic corrosion due to different anodic index between the bolt and a plate

Galvanic series of Metals (Anode End to Cathode End)

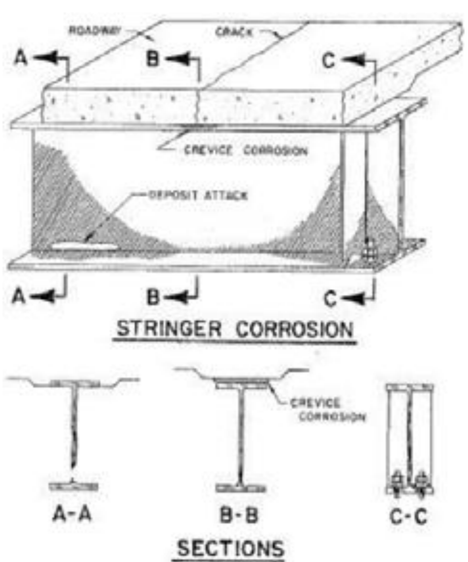
ANODE → CATHODE

1. Magnesium	9. Nickel (Active)	17. Stainless Steel 304 (Passive)
2. Zinc	10. Inconel 600 (Active)	18. Stainless Steel 316 (Passive)
3. Aluminium alloys	11. Brasses	19. Titanium
4. Aluminium	12. Copper	20. Haste alloy C276
5. Mild Steel	13. Bronzes	21. Silver
6. Cast Iron	14. Nickel (passive)	22. Graphite
7. Stainless Steel 304 (Active)	15. Inconel 600 (passive)	23. Gold
8. Stainless Steel 316 (Active)	16. Monel 400	24. Platinum

b. <u>Crevice Corrosion:</u>

Crevice corrosion is a highly penetrative type of localized corrosion that occurs in or directly adjacent to gaps or crevices on the surface of a metal. These crevices can be the result of a connection between two surfaces (metal to metal or metal to non-metal), or by an accumulation of deposits (dirt, mud, biofouling, etc.). This type of corrosion is characterized by deterioration in the area of the crevice.

One of the main criteria for the development of crevice corrosion is the presence of constant water within the crevice. This lack of fluid movement gives rise to the depletion of dissolved oxygen and an abundance of positive ions in the crevice. This leads to a series of electrochemical reactions that alters the composition of the fluid and makes it acidic in nature. The acidic liquid in the crevice breaks down the metal's passive layer and renders it vulnerable to corrosion attack.



Crevice corrosion in beams

c. Pitting Corrosion:

Pitting corrosion, also known as pitting, is another localized form of corrosion that occurs on metal surfaces. Pitting typically manifests itself as small diameter cavities or holes on the object's surface while the remainder of the metallic surface remains less affected. This form of corrosion is also highly penetrative and is considered to be one of the most dangerous types of corrosion because it is difficult to predict and has a tendency to cause sudden and catastrophic failures.

Pitting usually originates on areas of the metal surface where inconsistencies in the protective passive film exist. These inconsistencies may be due to film damage, poor coating application or foreign deposits on the metal surface. Areas where passivity has been reduced or lost now become the anode while the surrounding regions act as the cathode. In the presence of moisture, the anode and cathode form a corrosion cell where the anode (i.e., the areas unprotected by the passive film) corrodes. Because the corrosion is confined to a localized area, pitting tends to penetrate the thickness of the material. The formation of pits is often a precursor to other forms of localized failures such as metal fatigue and stress corrosion cracking (SCC).

Pitting corrosion of steel columns in a detergent manufacturing plant due to the presence of salt and active matter.

Pitting corrosion of steel beam in a salt manufacturing plant

d. Stress Corrosion

Stress corrosion cracking (SCC) is a form of corrosion marked by the formation of fine cracks on specific areas on the metal surface while

the metal remains less affected over most of its surface area. Often noticed initially as surface cracks, they progressively join each other in areas with likelihood of locked-in residual / tensile stresses during the process of fabrication – welding, heat treatment and cold deformations. SCC is considered to be an insidious form of corrosion because the damage is sometimes not immediately detected during inspections, which suddenly aggravates to cause rapid loss of strength and consequent failure.

Effects of corrosion on steel structure and major accidents reported due to corrosion:

The corrosive reaction changes the microstructure of the steel on its surface, thus making it brittle and flaky. Slowly it loses its mechanical strength and elasticity. Thus, the useful life of steel structures and other applications are severely curtailed. Non – uniform corrosion such as pitting, crevice, galvanic and SSC are dangerous forms of corrosion that may lead to sudden and catastrophic failure.
Some of the major failure incidents are listed below:

NAME OF ACCIDENTS	YEAR	PLACE	REASON AND DAMAGE
Silver Bridge Collapse	1967	Ohio, USA	The U.S. highway 35 bridge in between Point Pleasant, West Virginia and Kanauga, Ohio fall down into the Ohio river. Stress corrosion cracking and corrosion fatigue was responsible for this collapse. This accident claimed over 46 lives.
Bhopal Accident	1984	Bhopal, India	Methylisocyanate (MIC) storage tank leaked due to corroded pipelines, valves, and other safety equipment at Union Carbide India Ltd. caused the release of MIC and other chemicals into the surrounding area. Almost 3000 people killed, and over 500,000 people were injured.

Rupture of a High-Pressure Vessel	2009	Illinois, USA	Stress Corrosion Cracking of the walls of a pressure vessel causes Nihon Dempa Kogyo (NDK) Company explosion.
Swimming Pool Roof Collapse	1985	Uster, Switzerland	After 13 years of use, the concrete roof supported by stainless steel beams collapsed due to stress corrosion cracking.

Corrosion Prevention and Management:

Corrosion is the biggest single cause of plant and equipment breakdown in the industry. However, corrosion is often not uniform and it is estimated that only 35 % failure of a chemical plant are due to general / uniform corrosion. The most common cause of corrosion failure have been discussed above. Most of these can either be controlled or eliminated if proper measures are adopted.

Some of the measures are:

a. Material Selection
b. Anodic and cathodic protection
c. Engineering design of components
d. Use of special coatings and other sophisticated surface protective applications

a. Material Selection:

Since the materials available for fabrication of equipment and structures are large, the factors, such as, resistance to corrosion in a given environment, peculiar tendency of materials to specific types of corrosion, and special treatments should be coordinated with the functional parameters. Strength, fabricability, ease of production, appearance, availability and cost should be considered. It may be necessary to compromise and sacrifice some advantageous properties to satisfy corrosion requirements and vice-versa. Using fully corrosion resistant material is not always the correct choice; a balance between the first cost and the cost of subsequent maintenance should be found over the full estimated life of the desired utility.

Certain combinations of metal and compatibility are a natural choice. These are:

Materials of Construction	Ideally used in
Aluminium	non-staining atmospheric exposure
Chromium containing alloys	oxidizing solutions
Copper and alloys	reducing and non-oxidizing environments
Hastealloys	hot hydrochloric acid
Lead	dilute sulphuric acid
Monel	hydrofluoric acid
Nickel and alloys	caustic, reducing and non-oxidizing environments
Steel	concentrated sulphuric acid
Tin	distilled water
Titanium	hot strong oxidizing solutions
Tantalum	ultimate resistance

b. Anodic and cathodic protection:

Dissimilar metals in intimate contact or connected by a conductive path should be used only when the functional design or other important consideration render them unavoidable. Wherever possible, select materials in contact, close together in the EMF series. Exposed area of less noble metals should be kept large, relative to more noble metals. If joining of non-compatible metals is unavoidable, dielectric separation is imperative. This can be provided in many ways as for instance insulating, gaskets and protective coatings. Figures 5.A and 5.B show ways in which corrosion is prevented in such cases. In Fig. 5.A apart from the use of dielectric insulation separating the aluminium footing and steel pad, a zinc chromate primer may be used to cover surfaces in contact. In Fig. 5.B instead of using a copper coil, a nickel plated copper coil is preferable.

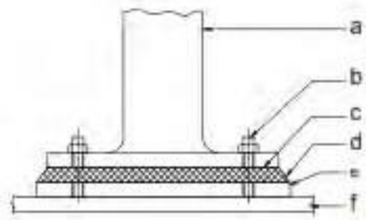


Fig. 5.A Dielectric Separation of Metals: (a) Aluminium Footing, (b) Stainless Steel Stud, (c) Dielectric Insulation, (d) Sealant, (e) Steel Pad, (f) Steel Plate

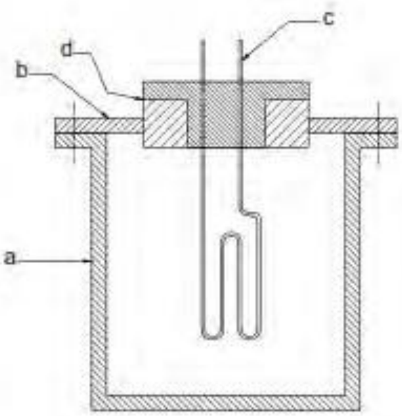


Fig. 5.B Dielectric Separation of Metals: (a) Galvanised Steel Tank, (b) Cover, (c) Nickel Plated Copper Coil, (d) Insulation

c. <u>Engineering design of components:</u>

The main considerations which will help to prevent corrosion are essentially based on an appropriate shape of the component, concentration of stresses due to loading, the surface conditions and precautions in fabrication.

Each component will have to be designed to avoid concentration cells and crevice corrosion. Crevices can be avoided by using welded joints in preference to bolted or riveted joints. Unavoidable crevices as shown in Fig. 5.C may be caulked or sealed.

Whenever possible, horizontal surfaces exposed to the atmosphere should be avoided, since these tend to hold moisture and dirt. Dish-end heads for vessels are preferable to flat heads.

Opportunities for the collection of concentrated solutions and corrosive materials at inaccessible positions in liquid-carrying equipment must be minimized. For example, provision is required to be made for the complete drainage in tanks and vessels (Fig. 5.D). Inlet or outlet nozzles must not project into the vessels and tanks.

Crevices, sharp corners and projections are causes for corrosion-erosion attack. Uneven stress distribution should be avoided in corrosive conditions. Localized stresses in any metal component intensify corrosion, viz., drilling of bolt holes sets up unequal stress distribution.
The area surrounding the hole becomes anodic and is thus susceptible to attack in a corrosive environment.
To relieve stresses in fabrication such as welding, machining, forging, etc., stress relief through heat treatment should be specified. Rough surfaces are more susceptible to corrosion than smooth surfaces. Likewise, projections and sharp corners are prone to corrosion-erosion failures. All fabrication marks, rough joints, weld heads and pipe burrs should be removed. Welded joints should be ground flushed.

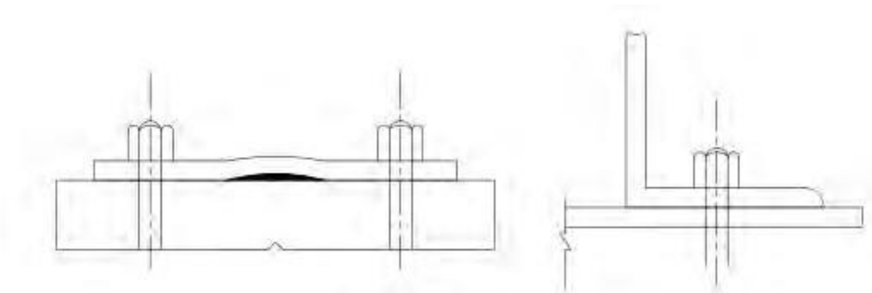


Fig. 5.C Crevices

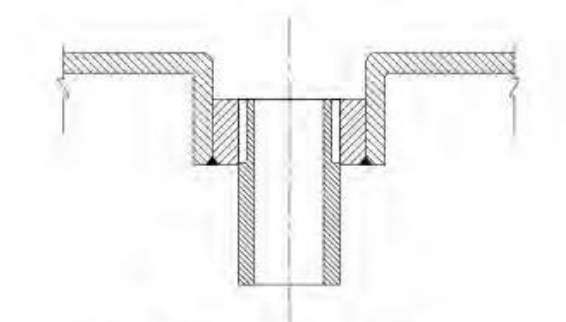


Fig. 5.D Drainage from A Tank

d. Use of special coatings and other sophisticated surface protective applications:

Protective methods comprise of providing separation of surfaces from environment, cathodic protection or anodic polarization. These methods can be used individually or in various combinations. Separation of materials from environment, provided by application of metallic coatings, by joining, coating with plastics or ceramics, by lining, sealing, enveloping, and insulation and by application of temporary protectives (oils, greases, removable plastics, etc.) involves primarily a change in the surface composition and this change is brought about by additions of different materials in the form of an outer skin. Most of these processes involve a dimensional change and a weight change.

Cathodic protection is the application of a direct current from an auxiliary anode to prevent or retard the corrosion of metal which has been made the cathode in the corroding media. For example, by installing an anode near a metal component of the structure, the areas of the metal (anodic or cathodic) within the range of the electrolyte all become cathodic. This current, when properly applied, opposes the corrosion current from the surface of the protected metal and will minimize corrosion.

Electrolytic anodes are used with external power source, and may be either sacrificial or non-sacrificial. Sacrificial or expendable anodes may be iron, steel or aluminium. Aluminium is preferred due to its light weight, uniform corrosion rate and white or colorless corrosion-products. Non-sacrificial anodes may be platinum, high-silicon iron, graphite and carbon. These are more expensive but last longer. Cathodic protection is used to protect pipelines, tanks, heat exchangers, etc.

Inhibitors are also used for control of corrosion. This is in the form of a chemical, which, when added in small amounts to the corrosive medium, markedly reduces the rate of chemical attack. They are believed to form and maintain upon the metallic surface a protective film, which decreases the corrosion current and renders the environment non-reactive. Inhibitors can control either the anodic or cathodic corrosion reaction and are, therefore, known as either anodic or cathodic inhibitors. Anodic inhibitors include chromate, silicate, and nitric salt of sodium and potassium. Glassy phosphates and many organic compounds function as cathodic inhibitors. Cathodic and anodic inhibitors acting together are more effective than either of them separately. In addition to above, protective coatings and linings are used for vessels, piping (pips, bends and valves) and storage tanks, as protective means.

Protective Coatings:

Quite often limitations are imposed by cost and fabrication requirements on the choice of the most desirable material for resisting corrosion. Therefore, a protective coating on a less resistant metal or alloy represents a practical compromise. There are three general categories of coatings: metallic, inorganic and organic. A coating should be applied only on a clean surface. The presence of grease, oil, dirt or scale adversely affects the adherence, continuity and durability of coatings. The surface preparation is one of the most important acts for the durability of coatings.

Metallic Coatings:

Many different techniques are practiced commercially for applying metallic coatings. These can be classified as anodic or cathodic. The anodic processes will protect the coated metal through their preferential corrosion, whereas the noble metal coatings are mainly used for their superior corrosion resistance properties. The most common methods are hot-dipping, cementation, mechanical cladding, electroplating, metal spraying and condensation of metal vapors. Carbon steels are some of the most commonly coated metals.

An important method of metallic coating is cladding, which is of interest in the pressure vessel industry. The cladding metals in the form of thin plates are bonded to the backing steel plates either by hot rolling or by explosion cladding. The backing plate is ordinarily of plain carbon steel, but for special applications low alloy steels can also be used. The cladding metals are stainless steels, mainly austenitic types, nickel, monel, copper and cupro-nickel.

Cladded plates are economical, since the corrosion resistance of special cladding metals is obtained, by the use of only a thin layer of the material. Cladded plates can be fabricated by cutting, shearing, welding, etc.

Inorganic Coatings:

Commercial inorganic coatings for protection of metals fall into two general categories, namely, chemical or electrochemical surface conversion treatments and vitreous enamels. Those in the first group often do not constitute the final protective layer but serve as an undercoating for paint or other organic materials. Chemical dip methods are employed to create protective oxide films on iron, steel, stainless steel, aluminum, copper and some of their alloys. Such films are usually very thin and are frequently colored. Electrolytic coatings may be made, as in the case of anodizing treatments for aluminum which produce a relatively thick, abrasion resistant coating.

Vitreous coatings although brittle, possess surface hardness and complete inertness to many corrosive environments. Enameled or glass lined vessels and other equipment are available in a variety of shapes and sizes. These enamels are made from fused silicates of various compositions, containing colloidal suspensions of coloring materials. For metallic sheets, the enamel is applied as slurry. Subsequent heating conditions are dependent on enamel composition and intended service.

Organic Coatings:

These represent a large variety of materials and are the most widely used methods of protecting metals against corrosion. More than a thousand different synthetic resins, as well as a wide variety of pigments, modifying oils and solvents are used in coating formulations. These coatings protect metals by interposing a continuous, adherent, inert film between the metal and its environment. They also markedly change the appearance of the metal. These coatings can be divided into three classes. Paint is a dispersion of pigments in a vehicle which consists of drying oils modified with a solvent or thinner to aid in the application. Enamel is a dispersion of pigments in varnish or resin vehicle which polymerizes either by oxidation at room temperature or by application of heat. Lacquer is a pigmented natural or synthetic resin dissolved or suspended in solvents. Powder coating is effectively carried out by applying a polymer by a spray or an electrostatic spray followed by baking at high temperature. This results in a uniform continuous coating.

Linings:

Storage tanks, reaction vessels, pipes, ducting, etc. are covered with linings in order to (a) give the underlined structure protection against chemical attack, (b) prevent contamination of materialsbeing processed, and (c) minimize the effect of abrasion. The various materials commonly used for linings are rubber, lead, glass, plastic, acid proof bricks, etc. Fiber glass lining either Fiberglass Reinforced Epoxy (FRE) or Fiber Reinforced Polymers (FRP) are also widely used nowadays.

Case study of corrosion in a Spray Drying Tower used for producing blown detergent towers:

Pictures of corrosion of spray drying tower

<u>Analytical approach</u>:

A. Observations - directly related to corrosion:

1. . The NDT report shows that there are varying degrees of corrosion in the entire tower. However, the corrosion seems to be more prominent and concentrated at the top support level of the tower where the feed to the spray dryer is likely to come in contact first with the shell; while not desirable, it cannot be completely avoided.

   From the nature of the corrosion, as seen in the photographs, it appears to be the result of pitting and stress.

   Although, the full composition of the feed to the dryer is not known, it has been mentioned by the manufacturer that the feed contains salt as one of the constituents.

   Keeping both these observations in mind, it is highly possible that one of the main reasons for corrosion is chloride stress.

2. . The tower is constructed out of carbon steel SA515 / 516 Grade 60 / 70 and is not lined.

   While lining or cladding is necessary to prevent exposure of the carbon steel and consequent deterioration, it must be pointed out that SS304 is not the right material to withstand the operating conditions. There are other grades of stainless steel such as SS316 or Duplex 2205 with higher content of nickel, chromium and molybdenum which are better suited from the corrosion point of view.

   Moreover, plug welding of the SS sheets to the parent metal locks in further stresses which contributes to chloride stress corrosion, normally seen as fine cracks. Further, technology has progressed with respect to techniques of linings. If cost is not the primary consideration, then "CLAD STEEL PLATE" produced by superior methods of bonding can be used.

However, for selection of the material of cladding, the composition of the feed must be known in far greater detail – if not the exact composition – at least the pH value and the salt content.

CLAD STEEL PLATE

3. It is not yet determined whether the corrosion is from inside to outside or outside to inside because inspection of the inside of the tower is not possible unless it is shut down and also insulation on outside surface will need to be removed for inspection of the external surface of the shell.

Further, it has been mentioned that the insulation of the tower is rock wool which contains chemicals that can contribute to corrosion and is also hydrophilic in nature.
While glass wool is unsuitable for the cylindrical part of the tower because of heat, there are more appropriate options such as silica based aerogels and composite pyrogels, etc.

Therefore, it must be ascertained whether the corrosion is from inside to outside or outside to inside or a combination of both to understand whether corrosion is purely stress related or a combination of both chloride stress attack and reaction of insulation material.

B. Other Observations – not directly related to corrosion, but important in the overall considerations:

1. . The tower is supported at two floor levels. Due to the increase in the number of supports at multiple levels, there will be zones of stress concentration, particularly, the locked in residual stresses at the welded connections and reversal stresses due to restraints to expansion and contraction of the shell. These factors enhance the vulnerability to chloride stress corrosion.

   Ideally the tower must be supported directly on columns with footings. Such supporting arrangement can also be designed by optimizing the load transfer path and foul checking with respect to the grade beams and foundations of the existing structure.

2. . It has been reported that the external surface of all the tower is painted "silver" (presumably referring to the "color" but it is assumed that the paint is aluminum based).
   The exterior of the tower that is the parent metal side must be protected with suitable heat resistant coatings such as silicone base paints, multi-polymeric high build primer, etc. before insulating it.

This brief note must be considered as a preliminary attempt to identify the possible reasons for corrosion and suggested remedies.

REFERENCES

1. FEMA corrosion protection for metal connectors in coastal areas
2. www. corrosionpedia.com
3. . Joshi's process equipment design by V.V.Mahajani and SB Umarji.
4. . Corrosion of steel reinforcement by C.Andrade, Institute of Construction Science, Madrid, Spain
5. . Industrial Corrosion Management by U.Kamachi, Honorary Professor of Practice, IIT Madras

TRANSITIONING TO HIGH STRENGTH STEEL FOR STRUCTURAL APPLICATIONS

Tamilselvan
[PhD scholar, Earthquake Engg Dept, IITRoorkee]
Sahil Aggarwal
[Sr Technologist, PAG, Tata Steel]
Dr PC Ashwin Kumar
[Asst Prof, Earthquake Engg Dept, IITRoorkee]

INTRODUCTION

Application of high strength steel in structures aids in achieving higher economy, whichhowever is accompanied by decrease in ductility and section size. This leads to increase in stress rangeand possibility of pre-mature failure of section due to local and/or global instabilities in the members. Variation in the nominal to expected yield and ultimate strength can also become critical in structures where strong column-weak beam philosophy has to be achieved for better performance.

Steel structural systems like moment resisting frames (MRF), concentrically braced frames (CBF) and eccentrically braced frames (EBF) included in steel design code IS 800:2007, are popularly used in industrial as well as commercial buildings. These systems depend upon deformation-controlled elements like beams in MRF, braces in CBF and link elements in EBF to dissipate energy during an extreme loading condition like earthquake, so as to act like a "fuse" and safeguard the critical gravity load carrying members like beam and column (force-controlled elements). This hierarchy of member and connection's strength and ductility, which consequently affects the overall performance of the structure can only be achieved if an engineer understands the steel material characteristics in the elastic and inelastic stages as well as has design procedures accommodating the higher strength of steel. IS800: 2007 guidelines allow use of E250B grade in MRF and CBF and additionally the inclusion of 27 J energy criteria requirement can push this to E350 grade as per IS 2062:2011. International codes allow higher grade steels for force controlled elements, which can lower the cost of the structure. However, as mentioned above the use of higher strength steel has to be done with caution, especially in the case of built-up sections, where information about the performance of high strength steel plates at material level, component level as well at an assembly/frame level are not available in plenty.

As a first step towardstransitioning into utilizing higher strength steel and using advanced design methodology like performance-based design to economically build structures that achieve specific targeted performance under extreme loading condition like earthquake, material characterization of three grades of Indian steel E250, E350 and E450 has been taken up.

MATERIAL CHARACTERIZATION STUDY

The ongoing study currently focuses on base metal characterization of different grades of steel. This is being done through exhaustive monotonic as well cyclic testing of coupon test specimens extracted from the base metal. The specimen includes conventional coupon specimen as per ASTM E8 as well as various notched specimens [Fig. 1(a)]fabricated to develop varied stress triaxiality, lode angle and equivalent plastic strain, which can then be directly related to different structural systems as well as connections at the member level [Fig. 1(b)].

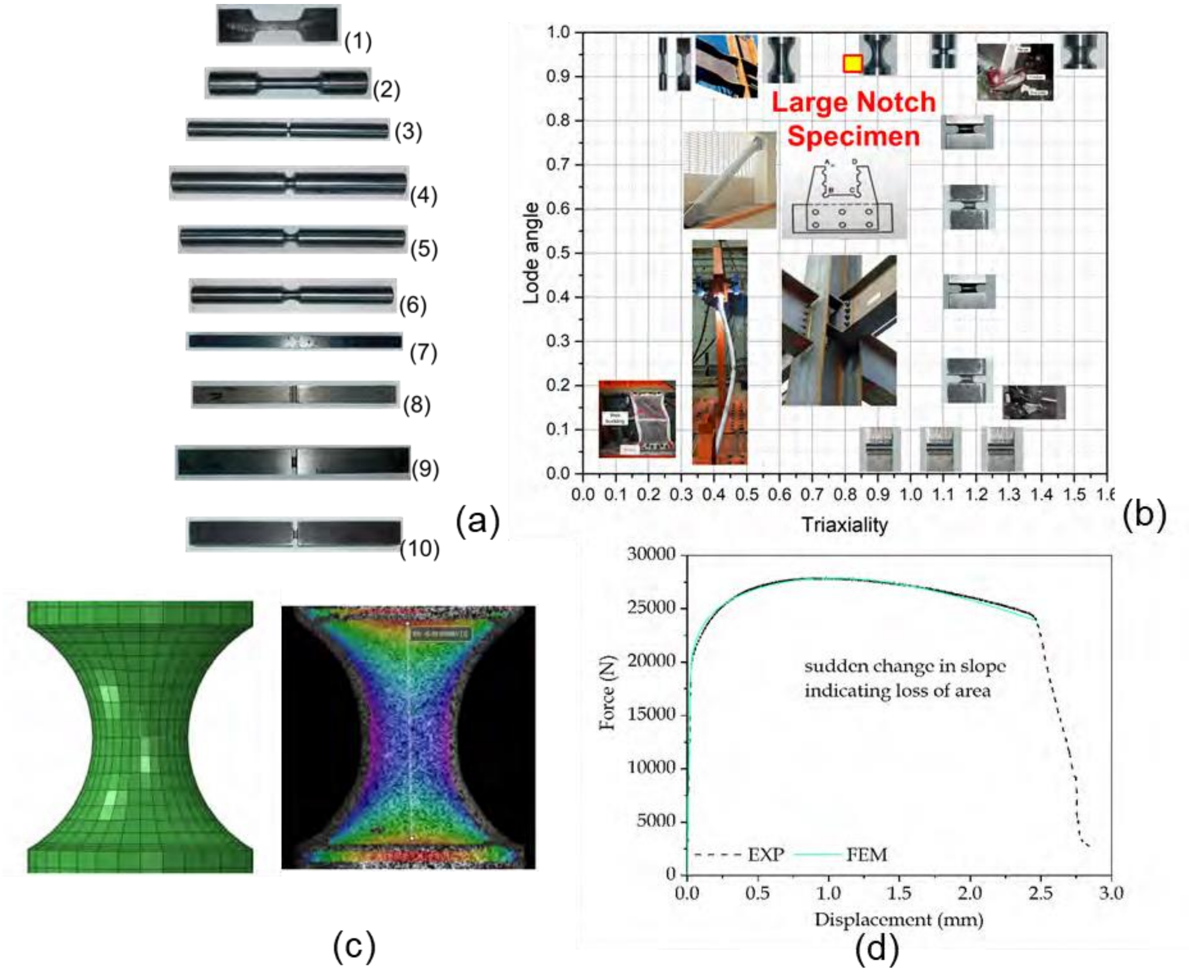


Fig 1: Material characterization study overview with results presented for one large notch specimen

Digital image correlation (DIC) systems have been used to acquire complete spectrum of data from the elastic stage, through plastic deformation phase to the final failure of the coupon specimen[Fig. 1(c)]. Numerical validation of the experimental tests has been conducted through finite element simulation to obtain parameters for the material constitutive model [Table 1] as well as the fracture locus. The validation of one of the large notch coupon specimens[(Fig. 1(d)] as well as its fracture locusis highlighted in [Fig. 1(b)]. This data will helpt he engineering community to move to economical and performance enhanced s tructural systems while appreciating and accommodating the changes required to incorporate high strength steel into design.

Table 1: Combined hardening parameters for differentsteel grades

Specimen	f_y (MPa)	Q_∞ (MPa)	b	C_1 (MPa)	G_1	C_2 (MPa)	G_2
LN (E250)	340	60	100	1500	7	200	4
LN (E350)	430	125	100	1500	7	200	4
LN (E450)	535	87.5	100	1500	8	200	4

REFERENCES

[1] IS800. (2007). " General construction in steel-code of practice." Bureau of Indian Standards, New Delhi.

[2] Bruneau, M., Uang, C. M. and Sabelli, R. (2011). Ductile design of steel structures. Second Edition, Mc-Graw Hill, NY.

[3] IS2062. (2011). "Hot rolled medium and high tensile structural steel – Specification." Bureau of Indian Standards, New Delhi, India.

[4] ASTM E8 / E8M-16a (2016). "Standard test methods for tension testing of metallic materials." American Association State Highway and Transportation Officials Standard No.: T68, American National Standard.