Application of Structural Steel in Multi-Storey Framed Structures

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Abstract: Steel is by some margin, the most popular framing material for multi-storey buildings. And has a long track record of delivering high quality and cost-effective structures with proven sustainability benefits. Steel can be naturally recycled and re-used continuously, and offers a wide range of additional advantages such as health and safety benefits, speed of construction, quality, efficiency, innovation, offsite manufacture and service and support. The steel sector is renowned for keeping specifiers abreast of the latest advances in areas such as fire protection of structural steel work and achieving buildings with the highest sustainability ratings,

Keyword: Structural steel design, RCC designs, by STADD.pro, fire proofing, corrosion proofing methods for structural steel. Comparison for RCC & structural frame

I. INTRODUCTION

Steel frames consistently capture a market share in the multi-storey non- residential buildings market of around 70% in many developing countries and cost advantages are often cited as a key reason in selection of the framing material. Advances in the science of fire protection by some system manufacturers have ensured that this cost continuous to fall, with the cost in real terms of fire protection today lower than it has ever been.

There is a great potential for increasing the volume of steel in construction, especially in the current development needs India and not using steel as an alternative construction material and not using it where it is economical is a heavy loss for the country.

II. WHY STEEL

IT'S ADVANTAGES:-

1. STRENGTH (Steel offers much better compressive and tensile strength then concrete)
2. SPEED OF ERECTION
3. PREFABRICATION
4. DEMOUNTABILITY
5. LIGHTER CONSTRUCTION
6. CAN BE EASILY RECYCLED

DISADAVANTAGES:-
1. REQUIRES FIRE PROTECTION
2. CORROSION PROTECTION
3. SKILLED LABOUR

III. OVER COME ON THE DISADVANTAGES

CORROSION :-
The durability of structures is given more emphasis in recent times. Durability and corrosion are considered as serviceability limit state criteria. A durable steel structure maybe defined as the one that performs satisfactorily the intended functions in the working environment under the anticipated exposure conditions during its service life without any deterioration of the cross sectional area and loss of strength due to corrosion.

Corrosion of steel is an electrochemical process which will not occur unless water and oxygen are both present on the steel surface. There are several types of corrosion. The result of surveys conducted in several countries shows that the annual loss due to corrosion amounts to several million dollars. However, with suitable corrosion control methods, the rate of corrosion can be made very slow or practically nil.

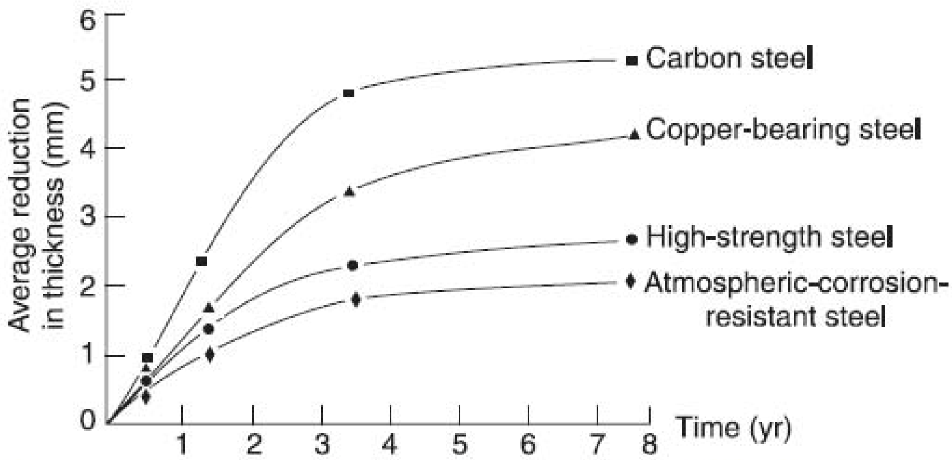
Many different methods have been used to protect steel against rust. The most obvious approach is to apply a protective coating to steel, thereby sealing of its surface from a corrosive environment. Painting, zinc coating and coating with various oils are examples of this method which has long been practiced. More recently, thermal spraying of other metals, organic paints and lining with rubber of porcelain enamel/plastic film lamination have come into use as protective coating for steel.

Another approach to corrosion protection is the use of steel that is not readily susceptible to rust. Adding certain elements to steel during its production can modify the inherent properties of steel so that a protective film form on its surface. This approach has produced stainless steel, first developed in 1910 and atmospheric corrosion-resistant steel, which appeared in the 1930s. Electric protection is used where a high corrosion resistance is essential or for structures such as steel piles.

Table comparison of chemical composition of various types of steel

Type of steel	Chemical composition (%)							
	C	Si	Mn	P	S	Cu	Ni	Cr
Carbon steel	0.16	0.009	0.57	0.010	0.010	0.11	0.025	0.036
Copper-containing steel	0.13	0.152	0.55	0.071	0.011	0.39	0.025	0.035
Atmospheric- corrosion-resistant steel (Type 1)1	0.11	0.467	0.30	0.119	0.021	0.39	0.410	0.640
Atmospheric- corrosion-resistant steel (Type 2)1	0.10	0.458	0.37	0.103	0.021	0.29	0.280	0.760

1Mo, Nb, Ti, V and Zr are also added (0.15% maximum in total)

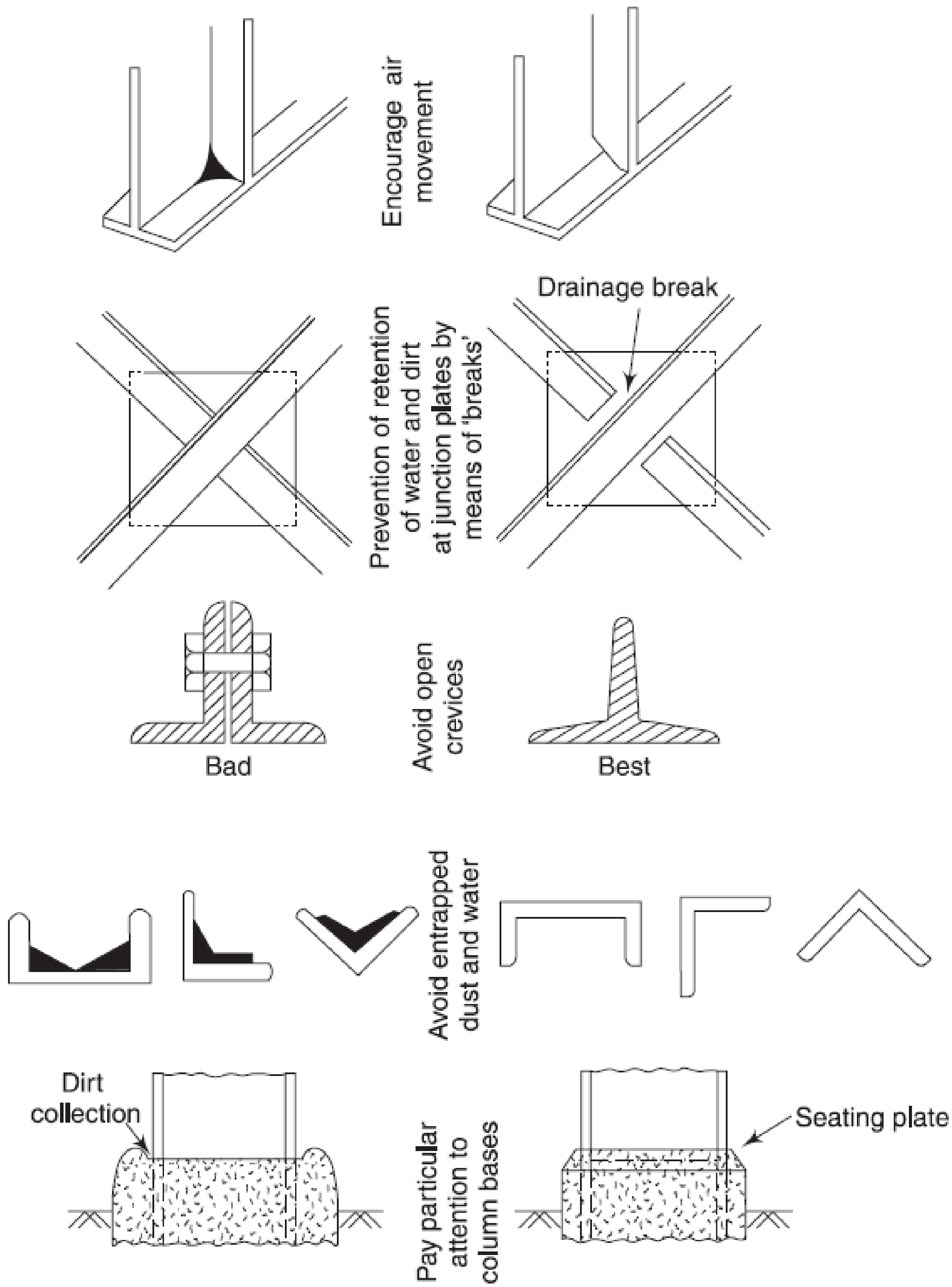


1 Comparison of weather resistance of steels (*Steel Today and Tomorrow* 1989)

Detailing to reduce corrosion

It is also important that the detailing of steel structures should be done in a way that enhances durability. Some of the points to be considered are (see fig. 15.14) as follows:

1. The detailing should avoid water or dirt entrapment or accumulation in corrosion points, such as sharp and re-entrant corners, cavities, welded rough surfaces to avoid corrosion due to accumulation of dust and moisture.
2. Discontinuous weld points, spot welds and tubular edge welds are also trouble spots of corrosion. All such points should be cleaned and filled or smoothed with tar-paint to protect from corrosion.
3. Detailing should provide suitable drainage breaks or holes wherever possible so that water does not accumulate.
4. Detailing should encourage free air movements such that the surfaces are dried rapidly.
5. Detailing should avoid crevices as far as possible.
6. Suitable access to all the components of the steel structure (especially the joint in a bridge) should be provided for periodic inspection and maintenance.
7. Detailing should avoid contact with different materials to prevent galvanic corrosion.
8. When friction grip bolts are used, protective treatment should not be applied to the faying surfaces.



Detailing to avoid water entrapment (ECCS 1998)

IV. FIRE RESISTANCE:

Traditionally, building codes specify regulations for buildings to be designed in such a way that they exhibit an acceptable level of performance in the event of fire (IS: 1641-1988, IS: 1642-1989, IS: 1643-1988, IS: 1644-1988). Essentially these regulations are only concerned with the prevention of premature collapse, the provision to evacuate occupants from the structure on fire, avoiding the spread of the fire to adjacent properties, thus reducing the risk to surrounding properties and their occupants. Thus, these regulations are not concerned with the effect of fire on the materials of the structure—this is a matter of concern only to the insurance companies and the owner of the property.

The earliest method of fire protection to steel structures was to encase the members with concrete. However this method is not used now, since the concrete encasing increases the dead weight of the structure and results in enlarged member sizes and foundations. Moreover, due to the time required for casting and curing, of concrete, the construction schedule gets delayed, resulting in an extra expenditure to the owner. Hence, alternate methods in the form of plaster or gypsum spray for beams, plasterboard encasement for columns and intumescent paints have been developed. It has to be noted that the fire protection of steel member is expansive. The typical cost of fire protection for multistory office blocks is around 15%-20% of the total costs; for the steel frame, the cost is around 10%-15% (Marin and Purkiss 1992).

It is possible to avoid such passive fire protection if special methods of construction such as slim floor or shelf angle floor are used, the basic steel member is overdesigned to give sacrificial protection, or fire resistant steel members are used. We can also use such unprotected steel work where the temperatures developed in a fire are insufficient to cause steelwork collapse. We will discuss these methods in this chapter. We will also discuss the methods to model a real fire and its effects on steel members.

Fire protection

Fire protection methods can be grouped into following two broad groups:

1. Fire prevention designed to reduce the chance of a fire occurring.
2. Fire protection designed to mitigate the effects of a fire when it eventually occurs.

Fire prevention methods include the elimination of possible ignition sources and the protection of the structural members. According to the phase of fire development in which they are used, fire protection methods can be classified as active and passive protection.

Active protection methods include the fire detection, alarm, extinguishing fire (fire extinguishers, fire hydrant, sprinklers), smoke control (smoke detection devices and venting features), and emergency exits (emergency staircase and lightning). The provision of adequate quantity of water fire-fighting purposes and its delivery using suitable pumps at the required places at the required pressure is also necessary. (It has to be noted that several multistorey buildings in India do not have emergency exits or staircase. The fire extinguishers kept in the building should be checked periodically; otherwise they will not be of any use. Efforts should be made to enable fire-fighting departments to be summoned promptly, to provide them with information as to the location and severity of fire and features of the building and facilities necessary to enable them quickly and safely tackle the fire.) All these methods can be operated either manually or automatically. These methods operate on the principle that early detection will lead to early fire- fighting and extinguishing of fire and reduce the risk of a large fire. For example, a combination of automatic sprinklers and smoke control systems has been used to help people to escape from fire in large multi-storey buildings. It has to be noted that these methods will not protect the structure completely from fire; these are designed mainly for the safe escape of people from buildings on fire (Roytman 1975; Nash and Young 1978).

Passive protection methods include structural fire protection, the layout of escape routes, the fire brigade access route and control of combustible materials of construction (Bushev, 1976 ; Buchanan 2001). For pre-flashover fires, selection of suitable materials for the building contents and interior linings will prevent\reduce the spread of fire. In post-flashover fires, passive measures will result in sufficient fire resistance to prevent both the spread of fire and structural collapse.

Often combinations of the above methods are employed; though the employment of and emphasis on any one method will result in the reduced use of the remaining methods (e.g., sprinkler installation may lead to reduced overall requirements of the fire resistance). No codes allow a total trade-off for sprinklers, but many national codes allow a 50% reduction in the fire resistance of the structural member if the building is provided with sprinkler. Eurocodes suggest that for calculating the fire resistance, the full load in a abuilding provided with sprinkler be taken as 60% of the designed full load.

Although steel is incombustible, its properties such as the yield strength and the modulus of elasticity are considerably reduced at high temperatures, which may result due to a major building fire. Due to the good thermal conductivity, the steel members may also ignite combustible material coming into contact with them. Hence it is necessary to provide some type of passive fire protection to the steel members if they are unable to withstand the fire loads. Some of the passive fire protection methods employed for structural steel members are discussed in NEXT section..

fire engineering design of steel structures

The study of steel structures under fire and their design provisions is known as fire engineering design. The basic consideration is that the building should be capable of maintaining its structural integrity during a fire over a period of time (determined by the actual fire condition and the required safety level) and at the same time protect its occupants and provide them with a safe means to exit.

fire resistance level

The required fire resistance level (FRL) is prescribed in the appropriate standards or building specifications or by the client. The FRL is specified in terms of the duration (in min) of standard fire load without collapse and depends on (a) the use to which the structure is put and (b) the time taken to evacuate the structure in the case of a fire.

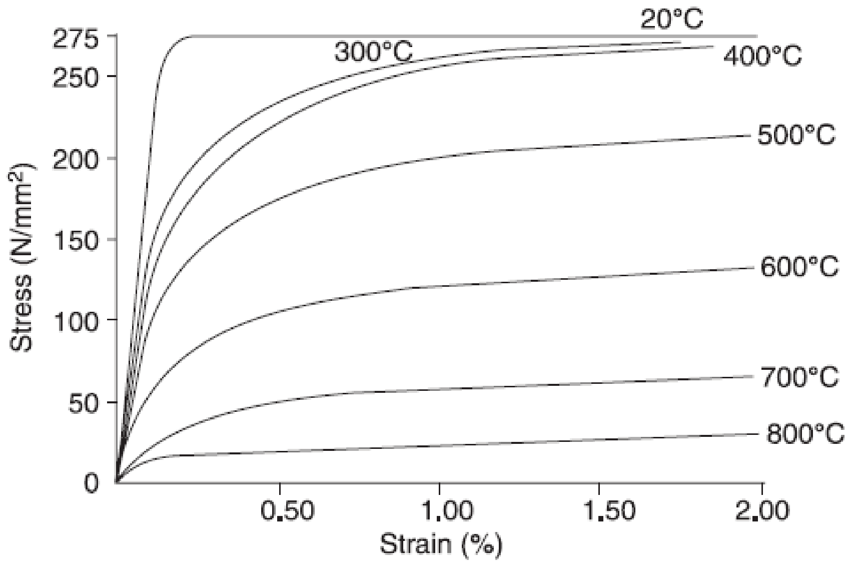
In India, the FRL is specified by IS: 1641-1988, IS: 1642-1989 and IS: 1643-1988 and varies from 30 min to 4 hr depending on the above two parameters.

period of structural adequacy

The period of structural adequacy (PSA) of a member is the time (in min) for a member to reach the limit state of structural adequacy when exposed to the standard fire test. It is the time for which the structural member will support the applied loads when subjected to a standard fire test. Thus the PSA of a member is the time it takes to fail when subjected to the standard fire such as ISO 834. Full scale testing is the most common method of obtaining fire resistance ratings (Buchanan 2001).

As per the code, the PSA shall be determined using any one of the following methods:

1. By calculation (i) by determining the limiting temperature of the steel (T1
   (ii) by determining the PSA as the time (t in min) from the start of test to the time at which limiting temperature is attained for unprotected members and for protected members.
2. By direct application of a single test.
3. By calculating the temperature of the member by using a rational method of analysis confirmed by test data or by structural analysis available in specialist literature, using mechanical properties which vary with temperature.



Typical stress–strain curves at elevated temperature for steel with $f_y = 275$ MPa

passive protection for steelwork

Various passive protection methods have been tried in practice. This include cladding the members with insulating materials (using spray protection, board protection, intumescent coatings, concrete encasements, etc.), circulating water using a system of hollow structural members, composite construction (in which the concrete slab provides thermal shielding), and partial encasement using precast slabs (e.g., in slim floor construction) or blockwork or double skin walls. These methods are discussed briefly in this section.

Fire protection systems

The traditional approach to the fire resistance of steel structures is to clad the members with insulating materials. The various alternative methods are chosen based on fire load, fire rating, and the type of structural members. These methods are discussed below briefly (Rains 1976):

Spray protection: in this method of protection, sprays containing asbestos-free materials (e.g., vermiculate or mineral fiber) in a cement or gypsum binder are applied on the structural member as a coating for a prescribed thickness. They are relatively low cost and can be applied at the site rapidly, even to cover complicated shapes. They do not suffer from the problems faced in using rigid boarding around the complex structural details. Mineral fiber fireproofing is generally spread with specially designed equipment. The equipment feeds the dry mixture of mineral fibres and various binding agents to a sprayer nozzle, where water is added to the mixture as it is sprayed on to the steel surface. This process is wet and messy and results in an undulating finish, which is unacceptable in public areas of buildings. The other important aspect of this insulation is the 'stick ability' of the material hence the cohesion and board protection (dry system).

V. BUILDING DISCRIPTION

The building considered here is an multi-storey building having G+11 stories located in BHOPAL , Madhya Pradesh seismic zone II and for earth quake loading, the provisions of IS: 1893(Part1)-2002 is considered the wind velocity 39 m/s, the plan of building is shown in figure 1 the building is planned to facilitate the basic requirement of resident. The building plan is kept symmetric about both axes. The plan dimension of the building is 20m x 16m with height of 33m above ground level, and foundations are situated 2m below the ground level. Height of each storey is kept 3m and the total height of the building is 33m.

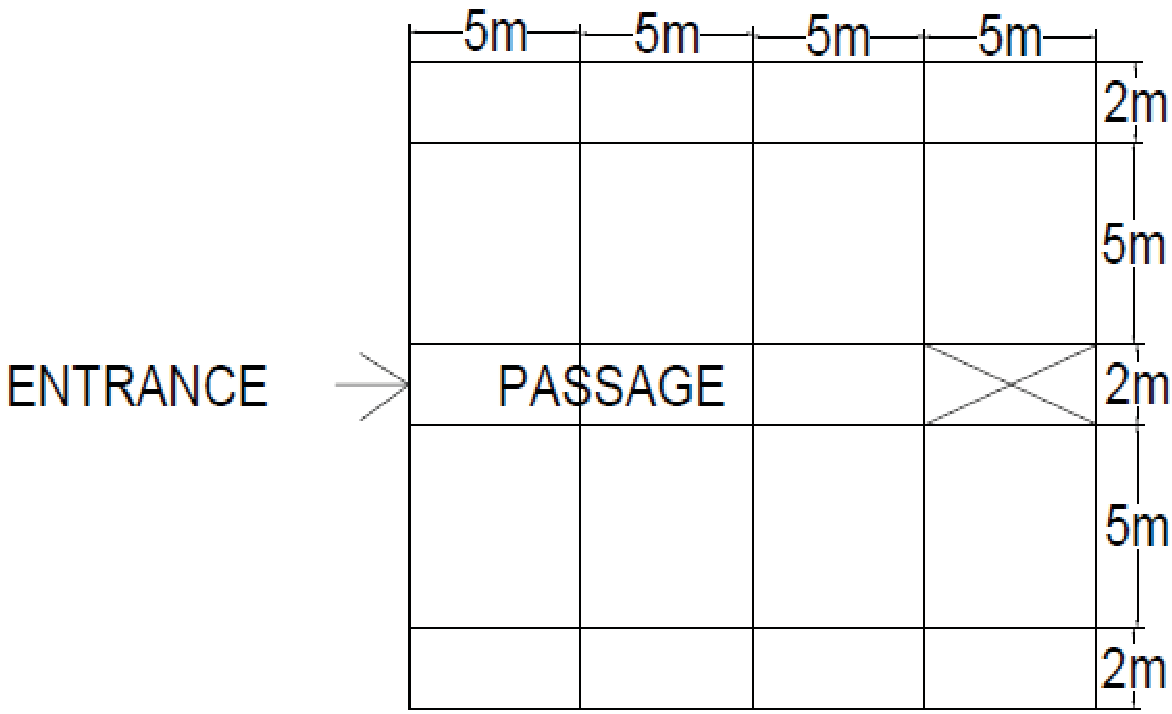


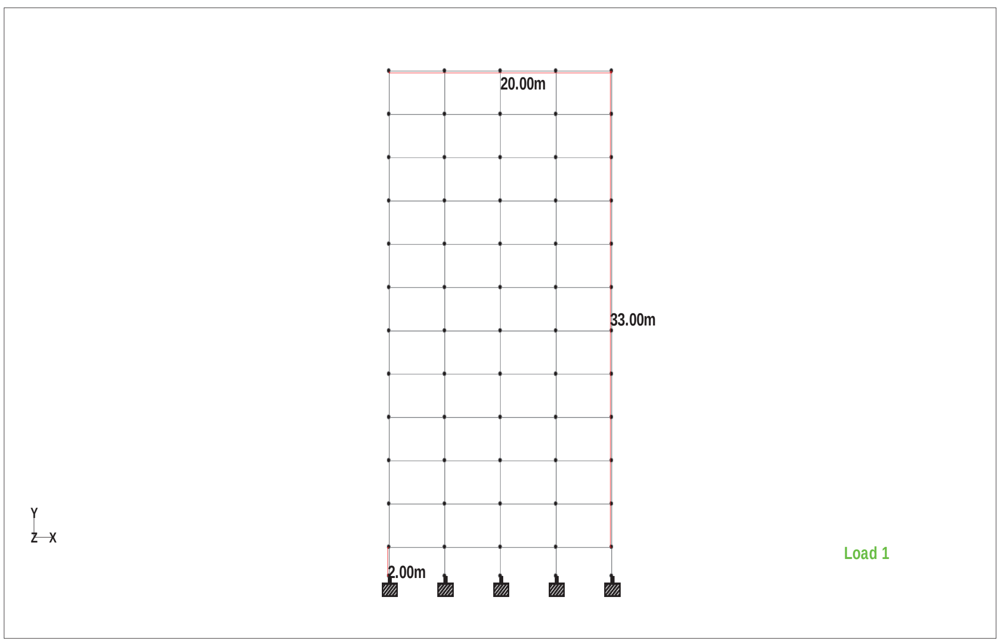
Fig. 1 LAYOUT PLAN OF BUILDING

The study is carried on the same building plan for RCC and Steel structure with some basic assumption made for deciding preliminary sections of both the structures. The basic loading on both type of structure are kept same. Other relevant data is tabulated in table below.

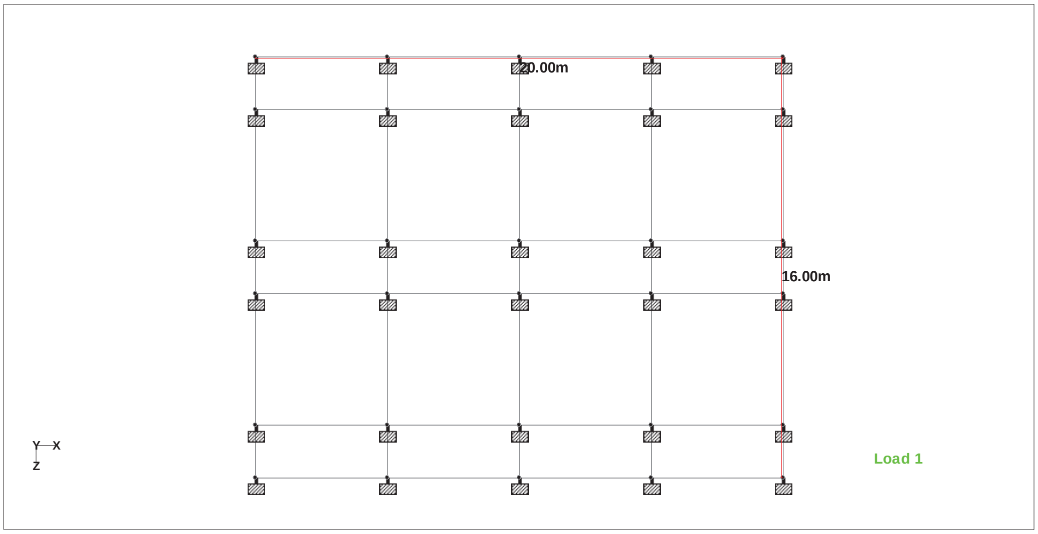
Table 1. comparison between RCC & STEEL framed structure

PARTICULARS	RCC STRUCTURE	STEEL STRUCTURE
Plan dimension	20m x 16m	20m x 16m
Total height of building	33m	33m
Height of each storey	3m	3m
Height of parapet	1m	1m
Depth of foundation	2m	2m
Size of beam	0.3m x 0.5m	ISHB 300H
Size of outer columns	0.5m x 0.5m	ISHB 450H TB
Size of interior columns	0.6m x 0.6m	
Thickness of slab	0.12m	0.12m
Thickness of floor finishes	0.05m	0.05m

Thickness of walls	0.230m	0.230m
Seismic zone	ZONE-II	ZONE-II
Soil condition	HARD SOIL	HARD SOIL
Response reduction factor	5	5
Importance factor as per IS: 1893(part 1)-2002	1.5	1.5
Zone factor	0.1	0.1
Live load at roof floor	1.5Kn/m^2	1.5Kn/m^2
Live load on other all floors	3Kn/m^2	3Kn/m^2
Grade of concrete	M-25	M-25
Grade of R/F steel	Fe-415	Fe-415
Grade of structural steel	-	Fe 410
Density of brick masonary	20kn/m^2	20kn/m^2

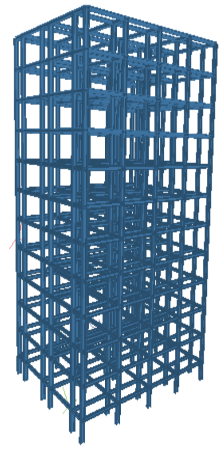


ELEVATION



PLAN

ANALYSIS & DESIGN BY STADD PROV8i



VI. VARIOUS LOADS ON STRUCTURE:-

1. DEAD LOAD
2. LIVE LOAD
3. SEISMIC LOAD
4. WIND LOAD

CALCULATION OF DEAD LOAD

All permanent construction of the structure form the dead load. The dead load comprise of the weights of walls, partitions, floor finishes, false floors and the other permanent constructions in the buildings. The dead load may be calculated from the dimensions of various members and their unit weights. The unit weights of various materials can be taken from IS 875 part I

Load on BEAMS	:- Member Load			
	Ht of GF Lev.Top to top of Beam	=	2.5	m
	Ht of FF Lev.Top io top of Beam	=	2.5	m
	Ht of Parapet	=	1	m
	Width of Wall	=	0.23	m
	Depth of FF Beam	=	0.5	m
	Depth of RF Beam	=	0.5	m
	Assume thickness of Slab FF	=	0.12	m
	Floor Finish	=	0.075	m
	Assume thickness of Slab RF	=	0.12	m
	Floor Finish	=	0.05	m

***		Wall Load On PB							
	1	X	1	x	0.23	x	2	x	20
							=	9.2	KN/M
							Say	10	KN/M
***		Wall Load On FB							
	1	X	1	x	0.23	x	2	x	20
							=	9.2	KN/M
							Say	10	KN/M
***		Wall Load On Parapet							
	1	X	1	x	0.23	x	1	x	20
							=	4.6	KN/M
							Say	5	KN/M

CALCULATION OF LIVE LOAD

Imposed load is produced by the intended use or occupancy of a building including the weight of movable partitions, distributed and concentrated loads, load due to impact and vibration and dust load. Imposed load do not include loads due to wind, seismic activity, snow and loads imposed due to temperature changes to which the structure will be subjected to creep and shrinkage of the structure, the differential settlements to which the structure may undergo.

Live Load

As per IS 875 Part II

On Floor	=	3	KN/M2
On Roof	=	1.5	KN/M2

CALCULATION FOR WIND LOAD

Wind is air in motion relative to the surface of the earth. The primary cause of wind is traced to earth's rotation and differences in terrestrial radiation. The radiation effects are primarily responsible for convection either upwords or downwords. The wind generally blows horizontal to the ground at high wind speeds. Since vertical components of atmospheric motion are relatively small, the term 'wind' denotes almost exclusively the horizontal wind vertical winds are always identified as such. The wind speeds are assessed with the aid of anemometers of anemographs which are installed at meteorological observatories at heights generally varying from 10 to 30 meters above ground.

DATA FOR CALCULATING WIND LOAD:-

CITY- BHOPAL

BASIC WIND SPEED Vb – 39M/S

CATEGORY – 3

CLASS - B

RISK COEFFICIENT (K1) – 1

TOPOGRAPHY FACTOR(K3) -1

TERRAIN, HEIGHT AND STRUCTURE SIZE FACTOR(K2) - CALCULATED IN TABLE BELOW.

HEIGHT (IN METRE)	K2	Vz=K1*K2*K3*Vb	Pz= O.6 Vz^2 (N/M^2)
9	0.880	34.32	706.80
12	0.904	35.256	745.80
15	0.940	36.66	806.40
18	0.964	37.596	848.10
21	0.985	38.415	885.5
24	1.000	39.00	912.6
27	1.015	39.585	940.2
30	1.030	40.170	968.2
33	1.039	40.521	985.2

CALCULATION OF EARTH QUAKE LOAD

DESIGN LATERAL FORCE

The design lateral force shell first be computed for the building as a whole. This design lateral force shall then be distributed to the various floor levels. The overall design seismic force thus obtained at each floor level shall then be distributed to individual lateral load resisting elements depending on the floor diaphragm action.

DESIGN SEISMIC BASE SHEAR

The total design lateral force or design seismic base shear (Vb) along any principal direction shall be determined by the following expression:

$$Vb = Ah\ W$$

Seismic parameters

IS CODE	:	1893-2002
ZONE FACTOR	:	0.1
RESPONSE REDUCTION FACTOR	:	5
IMPORTANCE FACTOR(I)	:	1.5
ROCK AND SOIL SITE FACTOR(SS)	:	2
DEPTH OF FOUNDATION	:	2 M

Seismic load generator:

The STADD seismic load generator follows the procedure of equivalent lateral load analysis. It is assumed that the lateral loads will be exerted in X and Z directions and Y will be the direction of the gravity loads. Thus for a building modal, Y axis will be perpendicular to the floors and point upword (all Y joint coordinates positive). For load generation as per the codes the user is required to provide seismic zone coefficient, importance factors, and soil charecteristic parameters. Instead of using the approximate code based formulas to estimate the building period in a certain direction, the program calculates the period using Raleigh quotient technique. This period is then utilised to calculate seismic coefficient C. after the base sher is calculated from the appropriate equation, it is distributed among the various levels and roof as per the specifications. The distributed base shears are subsequently applied as lateral loads on the structure. These loads may then be utilized as normal load cases for analysis and design

VARIOUS LOAD COMBINATION

1. 1(DL + LL)
2. 1.5(DL + LL)
3. 1.2(DL + LL $\pm$ EL)
4. 1.5(DL $\pm$ EL)
5. 0.9DL $\pm$ 1.5EL
6. 1.5(DL + WL IN X-DIRECTION) WINDWORD
7. 1.5(DL + WL IN Y-DIRECTION)WINDWORD
8. 1.5(DL + WL IN X-DIRECTION)LEEWORD
9. 1.5(DL + WL IN Y-DIRECTION)LEEWORD

QUANTITY ESTIMATION (RCC FRAMED STRUCTURE)

SR. N	ITEM	QUENTITY	RATE (AS PER CPWD DSR 2014)	COST(IN CRORE)
1	RCC			
	COLUMN + BEAM	1337.4 M^3	7530 Rs/M^3	
	FOUNDATION	142.21M^3		
	TOTAL	1479.61		1.1
2	STEEL			
	COLUMN + BEAM	1058 QUINTAL	4759 Rs./Q	
	FOUNDATION	100 QUINTAL		
	TOTAL	1158		0.55
	TOTAL COST INCLUDING ALL PARAMETER (MATERIAL, LABOUR, ERECTION ETC.)			2.75 CRORE

QUANTITY ESTIMATION (STEEL FRAMED STRUCTURE)

SR. N	ITEM	QUENTITY	RATE (AS PER CPWD DSR 2014)	COST (IN CRORE)
1	FOUNDATION			
	CONCRETE	106.321M^3	7530 Rs/M^3	0.08
	STEEL	80 QUINTAL	4759 Rs./Q	0.038
2	STRUCTURAL STEEL	3564.20 QUINTAL	4636 Rs./QUINTAL	1.65
	TOTAL COST INCLUDING ALL PARAMETER (MATERIAL, LABOUR, ERECTION ETC.)			1.768+1.1786 =2.5CRORE

VII. CONCLUSION

SUMMARY OF THE ECONOMIC BENEFITS OF STEEL CONSTRUCTION IN MULTI-STOREY BUILDING

SR.N.	ITEM	STEEL	RCC	REMARK
1	AREA	320M^2	320M^2	SAME
2	COST OF CONSTRUCTION (MATERIAL, LABOUR , ERECTION, MAINTANANCE)	2.90CRORE	2.75 CRORE	APPROXIMATE SAME
3	SPEED OF CONSTRUCTION	APPROXIMATLY 60% LESS TIME REQUIRED THEN RCC	MORE TIME IS REQUIRED AND CONSTRUCTION WORK IS VERY SLOW IN RAINY SEASON	TIME SAVING
4	BUILDING SELF WEIGHT	35.64T	344.9T	90% REDUCTION IN SELF WEIGHT
5	RESELL VALUE	APPROX 80% OF RESELL VALUE	NEGLEGIBLE	RICH SCRAP VALUE
6	EARTH QUAKE RESISTANCE	MORE EQ RESISTANCE THEN RCC DUE TO LESS SELF WT.	LESS EQ RESISTANCE THEN STEEL FRAME	MORE EQ RESISTIVE
7	FLEXIBILITY & ADAPTABILITY	PROVIDE LARGE COLUME FREE AREA THEN RCC		MORE CLEAR SPACE
8	SUSTAINIBILITY	STEEL IS 100% RECYCLABLE WITHOUT ANY LOSS IN QUANTITY		SUSTAINABLE
9	LOAD CONDITION	SAME	SAME	
11	SITE MANAGEMENT COST	SITE MANAGEMENT COSTS ARE REDUCED BECAUSE OF THE SHORTER		SITE MANAGEMENT COSTS CAN BE REDUCED BY 20 TO 30% WHICH CAN

		CONSTRUCTION PERIOD		LEAD TO A 3 TO 4% SAVING IN TERMS OF OVERALL BUILDING COST

REFERENCES

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CPWD DSR 2014

SOME IMAGES OF STEELSTRUCTURES