Design & Analysis of RCC Box Culvert using WSM & LSM

Bhutan Sakalkar[1] Roshan Kumar[2] Dr. Pankaj Singh[3]
[1,2]M.Tech. Scholar [3]Head of Department
[1,2,3]Department of Civil Engineering
[1,2,3]S.R.K. University, Bhopal, India

Abstract— As per standard practice bridges (Short Span less than 6M) were designed by IRC: 6 – 2000 & IRC: 21 – 2000. Both the codes were based upon Working Stress Method. But IRC has revised IRC: 6 – 2000 as IRC: 6 – 2014 and published a new code IRC: 112 - 2011 for bridges design. These are based upon the Limit State Method. In the present study using these codes a RCC Box Culvert of 4M span & height is analyzed & designed with WSM approach as well as LSM approach. A MS – Excel sheet is also developed by manual calculation for the same. Results of manual analysis, MS – Excel sheet & Staad Pro are compared for design the problem The Design based on both the approaches WSM & LSM are also compared & a parametric study is carried out by keeping Steel Grade as constant with different Grade of Concrete and finding the % reduction in Steel Reinforcement as well as % reduction in section dimensions due to LSM approach over WSM approach. This study will eventually comment on the design philosophy LSM & WSM regarding the design of RCC Box Culvert and discussed which one will perform better economically as well as structurally. The developed MS – Excel tool is user friendly, error free & fast for convenient-application for the RCC Box Culvert Design
Key words: RCC Box Culvert, WSM & LSM

I. Introduction

A culvert is a structure that allows water to flow under a road, railroad, trail, or similar obstruction from one side to the other side. Typically embedded so as to be surrounded by soil, a culvert may be made from RCC. Culverts are commonly used both as cross-drains for ditch relief and to pass water under a road at natural drainage and stream crossings. A culvert may be a bridge-like structure designed to allow vehicle or pedestrian traffic to cross over the waterway while allowing adequate passage for the water. Culverts come in many sizes and shapes including round, elliptical, flat-bottomed, pear-shaped, and box-like constructions. The culvert type and shape selection is based on a number of factors which include requirements for hydraulic performance, limitation on upstream water surface elevation and roadway embankment height.

Box culvert is one of the type of culvert that provide passage of traffic movement over an opening without closing of it and consisting a rectangular or square opening whose span and height of side walls is limited to 4m. It is suitable where the bearing capacity of soil is poor or discharge in the cross drainage structure is less. In such situation a box culvert is an ideal structure. The road level can be at top of box culvert or may be at some height due to earth fill or cushion above the box culvert.

II. Objectives of the Study

Present study “Analysis and Design of RCC Box Culvert using WSM & LSM” aims at collecting information on suitability of LSM approach for design of RCC Box Culvert. In India till 2014 bridge design was based on the working stress method. Relevant IRC codes were IRC: 6 - 2000 & IRC: 21 – 2000. Recently Indian road congress has revised IRC: 6 and published a new code for bridge design. These new codes i.e. IRC: 6 - 2014 & IRC: 112 - 2011 are based on limit state method. The objectives of the study include.

1) To analyzed and design RCC Box Culvert with both WSM and LSM approach
2) To develop MS-Excel sheet for analysis and design of RCC Box Culvert using two approaches
3) To work out material economy by compared the results of two approaches

III. Box Culvert

Bridges are provided at location of cross drainage structure. Depending upon the span, bridges are classified into three categories (I) Major Bridge (Span > 60M) (II) Minor Bridge (Span 6M to 60M) and (III) Culvert (Span < 6M). Depending upon the shape culverts can further be classified into (I) Slab Culvert (II) Box Culvert and (III) Pipe culvert. Normally Box culverts are provided for span up to 4.0M.

Box culvert is one of the type of culvert that provide passage of traffic movement over an opening without closing of it and consisting a rectangular or square opening whose span and height of side walls is limited to 4m. It is suitable where the bearing capacity of soil is low and discharge in the cross drainage structure is moderate. In such situation a box culvert is an ideal structure. The road level can be at top of box culvert or may be at some height due to earth fill or cushion above the box culvert (Figure 4.0).

Box culverts are economical due to their rigidity and monolithic action and separate foundation are not required since the bottom slab resting directly on the soil, serves as raft slab. For small discharges, single celled box culvert is used and for large discharges, multi celled box culverts can be employed.

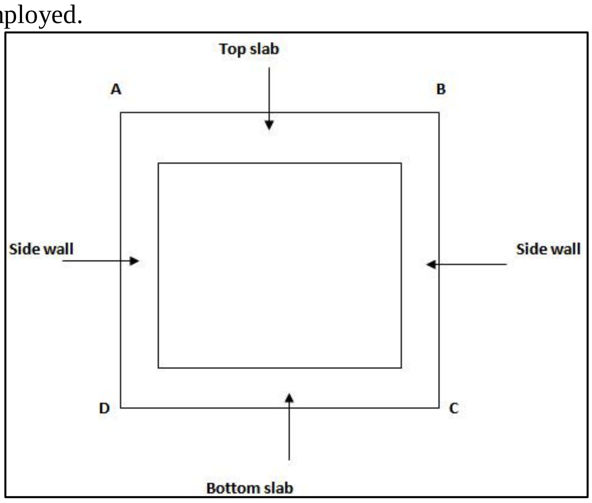

Fig. 4.6: Schematic Diagram of a RCC Box Culvert

IV. Components of Box Culvert

Box Culvert is comprised of top slab, bottom slab and side walls. All three components are rigidly connected to each other so that they can form a monolithic RCC structure. The various parts of Box Culvert are discussed below.

A. Top Slab

Top slab of Box Culvert forms the deck slab which will be in direct contact of moving traffic. Live Load makes the use of this top slab.

B. Bottom Slab

Bottom slab of Box Culvert is in direct contact of soil and resting over it. It is act as a raft foundation over the soil and transmits the load to the earth surface.

C. Side Walls

These are the wall held vertically and are in contact with earth-fill laterally to resist the earth pressure coming from the side fills. This is also resisting the water pressure from inside of Box Culvert if Box is full of water.

D. Cushion (If Present)

If top of box culvert is subjected to some embankment. In this case the top of the top slab are not in direct contact of traffic. The load of this earth fill surcharge or embankment over the top of the top slab is called as cushion load. The cushion height is generally vary 1M to 4M.

V. Loads of Box Culvert

All the parts of Box Culvert are subjected to the various loads. Their type and nature of action are as under.

A. Concentrated Load

Top slab of box culvert forms the deck slab. We converted the concentrated wheel load into uniformly distributed load calculated by using expression.

$$W = P\left[\frac{I}{\text{beff.}\times \ell\text{eff}}\right]$$

- Where W = uniformly distributed load on the slab
- P = wheel load as per IRC recommendations
- beff. = effective width of dispersion
- ℓeff. = effective length of load
- I = impact factor as per IRC recommendations

B. Uniform Distributed Load

The dead load of top slab or deck slab, wearing coat & weight of embankment or cushion (if present) is also considered to be uniformly distributed over the top slab and a uniform soil reaction will developed on the bottom slab.

C. Weight of Side Wall

The weight of two side walls will be acting as a concentrated load and is also assumed to be produced a uniform soil reaction on the bottom slab.

D. Water Pressure from Inside of Box Culvert

When box culvert is full with water, a water pressure from inside of wall is acting. The pressure distribution on the walls is assumed to be triangular with a maximum pressure intensity given by the expression.

p = w X h at the base
Where w = density of water
h = depth of flow

E. Earth Pressure on the Vertical Side Wall

There is also pressure of side earth fill on the vertical side walls For computing the earth pressure on the side walls of box culvert we make the use of Rankine and Coulomb Theory.

F. Uniform lateral Pressure on the Vertical Side Wall

The live load acting on the top slab of box culvert also produces a uniform lateral pressure on the side walls to some extent up to a particular height of side walls.

G. Advantageous of Box Culvert

5.7.1 The horizontal & vertical member of box culvert are made up of RCC slab that's why we can say the box culvert is a monolithic & rigid frame structure and its operation of construction is very simple.

1) The conventional slab culvert will require the abutment while box culvert has no abutment. In such situation box culvert is an economical & ideal structure.
2) The superimposed load as well as the dead load of box culvert is distributed uniformly over a wider area because bottom slab works as a raft foundation.
3) Box culvert makes the use of portion both below and above of top slab. Like above of top slab always use for movement of traffic and below of top slab may be used for traffic & cross drainage structure.
4) The problem of erosion & scouring of earth fill below a conventional slab culvert is almost completely reduced by the construction of box culvert.

VI. Standards Specifications

Indian Road Congress has defined various standards for the analysis and design of bridges. Indian Road Congress published various codes of design and revised them with the passage of time. Recently Indian Road Congress revised IRC: 6 - 2000 as IRC: 6 - 2014 & published a new code for bridge design IRC: 112 – 2011. Both are based on the Limit State method. These two newly published codes replaced the IRC: 6 – 2000 & IRC: 21 – 2000. They were used for bridge design based on the Working Stress Method.

A. IRC Loadings

There are currently 4 types of IRC loading as per IRC: 6 - 2014 which are considered as Live Load for Bridge design.

1) IRC Class 70R Loading

This loading is recently introduced in IRC: 6 - 2014. It consist the tracked loading as well as wheeled loading. We can say it is the advanced version of IRC Class AA loading (IRC: 6 – 2000). This loading has the highest magnitude in respect of all other IRC loadings. This loading is generally used for construction of bridges in industrial area and military area. The maximum load of a single wheel in case of IRC Class 70R loading is 350Kn. It is different from IRC class AA loading in longitudinal length of load which is 4.57M (Figure 3.0).

B. Impact Effect

In order to considered the effect of increase in stresses due to the dynamic action. Impact allowance is made as per the IRC codal provision. It is equivalent to the part of live load. It is taken into account to counter act the impact effect due to live load. Impact factor suggested by IRC: 6 - 2014 are follows.

1) For IRC Class A or IRC Class B Loading

I = (A/B+L)

Where I = impact factor

A = constant 4.5 for RCC bridges & 9.0 for steel bridges

B = constant 6 for RCC bridges & 13.5 for steel bridges

L = effective span of bridge.

2) For IRC Class 70R or IRC Class AA Loading

For RCC bridges designed for tracked vehicle 25% for span up to 5M and linearly reducing to 10% for span of 9M and for spans greater than 9M it is 10% up to a length of 40m. For RCC bridges designed for wheeled vehicle 25% for spans up to 12M and in accordance with the curve for spans exceeds to 12M.

C. Effective Width of Dispersion

The concentrated load on the bridge is not directly taken by the area exactly below the load. It is taken by the some effective area whose dispersion perpendicular to the span direction is known as the effective width of dispersion. Effective width of dispersion is calculated as per IRC clause B3.2 of IRC: 112 - 2011 only when span is supported on two apposite edges or along four edges when the span length is too more. Effective width of dispersion for one wheel is given by the following expression in the perpendicular direction of traffic movement.

$$b_{eff.} = \alpha \text{ x } (1- [\frac{x}{L}]) + b_w$$

Where beff. = effective width of dispersion

α = a constant depends upon [B/L] ratio

B = lane width

L = effective span

x = distance of center of gravity of load from the nearest support.

bw = width of concentrated area of load

bw = width of tyre + 2(thickness of wearing course)

D. Effective Length of Load

In the same manner of effective width of dispersion the effective length of load for one wheel is given by the following expression along the direction of traffic movement as per IRC clause B3.3 of IRC: 112 – 2011.

ℓeff. = length of load + 2(thickness of top slab + thickness of wearing course)

ℓeff. = length of load + 2 (ttop + tw.c.)

Where ℓeff = effective length of load

ttop = top slab thickness

tw.c = wearing coat thickness

E. Reduction in the Longitudinal Effect for More than two Lane Traffic

Reduction in longitudinal effect on bridges having more than two traffic lanes due to the low probability that all lanes will be subjected to the characteristic load simultaneously shall be in accordance as per IRC clause 205 of IRC: 6 – 2014

F. Analysis & Design Condition of Box Culvert

Box culvert is treated as a Rigid Frame that's why The Moment Distribution Method is generally adopted for distribution & determination of final moments at the joints of frames or slabs. The box culvert is analysis & designed for following critical loading conditions.

1) Case-1 Box Empty

In such situation box culvert is subjected to the Live Load, Dead Load, Earth Pressure from outside, lateral pressure due to Live Load and No Water Pressure from inside of Box (Figure 6.0).

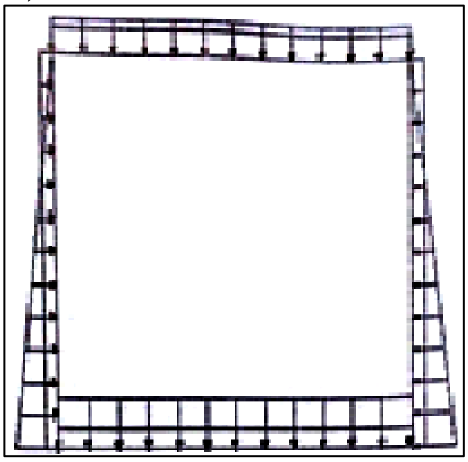

Fig. 6.0: Box Empty

2) Case-2 Box Full (With Live Load)

In such situation box culvert is subjected to the Live Load, Dead Load, earth pressure from outside, lateral pressure due to Live Load and water Pressure from inside of Box (Figure 6.1).

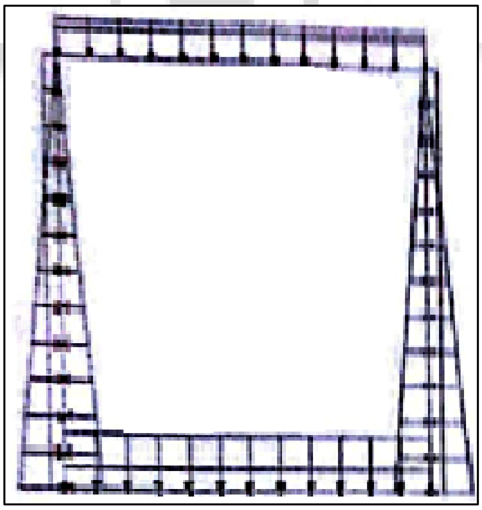

Fig. 6.1: Box Full (With Live Load)

3) Case-3 Box Full (Without Live Load)

It is the advanced case of Box Full. Where there is no live load on the top slab it will also come in the category of Box Full. In this case we don't provide such strength to the top slab because it is not subjected to any Live Load (Figure 6.2).

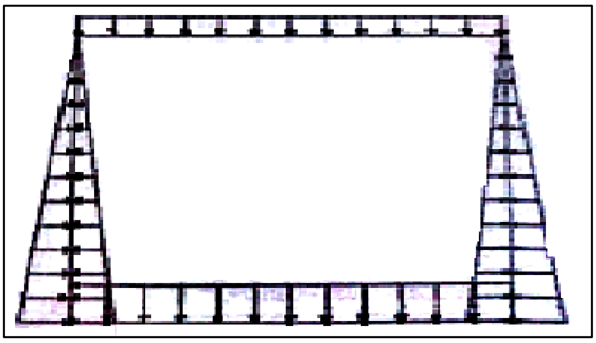

Fig. 6.2: Box Full (Without Live load)

G. *Design Load of Box Culvert*

For Top Slab Load Top slab load consists of top slab dead load, top slab live load and their nature & direction of action. The nature & direction of action are as follows.

VII. RESULTS OF ANALYSIS BY MS-EXCEL & STAAD PRO

The result of moment analysis by manual calculation, by developed MS-Excel Sheet and STAAD Pro are shown in Table 8.0.

	Bending Moments (Kn-M)			
Loading →	IRC CLASS 70R LOADING		*IRC CLASS A LOADING*	
Member ↓	*By MS-Excel Analysis*	*By STAAD. Pro Analysis*	*By MS-Excel Analysis*	*By STADD. Pro Analysis*
Bottom Slab	68.15	72.2	67.64	72.2
Top Slab	51.93	53.00	54.45	55.6
Side Wall	68.15	72.2	67.64	72.2

Table 7.0: Design Moments by MS-Excel tool and STAAD.Pro

A. *Design by MS-Excel tool*

1) *Effect on Area of Steel in WSM & LSM Approach*

A design of a RCC Box Culvert with Span & Height 4M is prepared with the help of developed MS-Excel tool. This design is based on the WSM as well as LSM approaches. From the developed MS-Excel tool the saving in the amount of steel area required with keeping a constant depth of section from WSM to LSM approaches is noted and from these noted data following figures and tables are developed (Table 7.1 and 7.2 & Figure 7.0 and 7.1).

Fe 415	IRC CLASS 70R LOADING	IRC CLASS A LOADING
CONCRETE GRADE	% DECREAMENT IN REINFORCEMENT	% DECREAMENT IN REINFORCEMENT
M30	7.54%	7.54%
M35	8.75%	8.75%
M40	9.84%	9.84%
M45	10.84%	10.84%

Table 7.1: Saving in Steel using LSM Approach over WSM for Fe415 Steel Grade

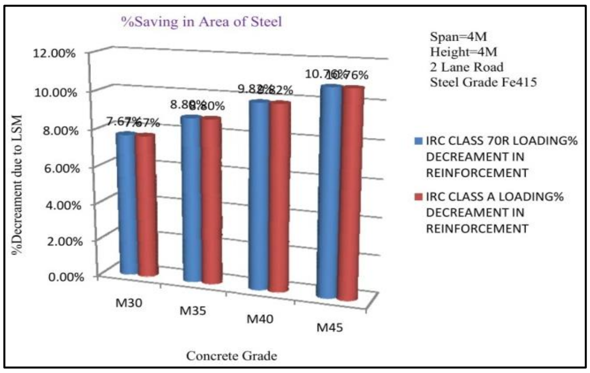

Fig. 7.0: Saving in Steel using LSM Approach over WSM for Fe415 Steel Grade

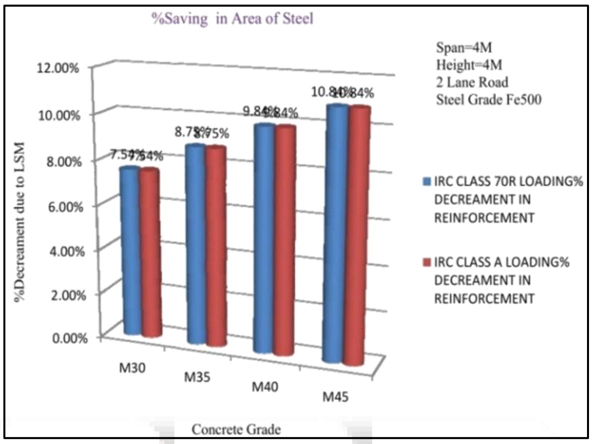

Fig. 7.1: Saving in Steel using LSM Approach over WSM for Fe500 Steel Grade

Fe 500	IRC CLASS 70R LOADING	IRC CLASS A LOADING
CONCRETE GRADE	% DECREAMENT IN REINFORCEMENT	% DECREAMENT IN REINFORCEMENT
M30	7.67%	7.67%
M35	8.80%	8.80%
M40	9.82%	9.82%
M45	10.76%	10.76%

Fig. 7.2: Saving in Steel using LSM Approach over WSM for Fe500 Steel Grade

2) *Saving in Depth of Section in LSM over WSM with constant Steel Area*

A design of a RCC Box Culvert with Span & Height 4M is prepared with the help of developed MS-Excel tool. This design is based on the WSM as well as LSM approaches. From the developed MS-Excel tool the variation in the amount of depth of section with keeping a constant steel area required from WSM to LSM approaches is noted and from these noted data following figures and tables are developed (Table 7.3 and 7.4 & Figure 7.2 and 7.3).

Fe 415	IRC CLASS 70R LOADING	IRC CLASS A LOADING
Fe415	% DECREAMENT IN DEPTH OF THE SECTION	% DECREAMENT IN DEPTH OF THE SECTION
M30	6.86%	6.85%
M35	7.91%	7.85%
M40	8..94%	8.93%
M45	9.90%	9.71%

Table 7.3: Saving in Material using LSM Approach over WSM for Fe415 Steel Grade

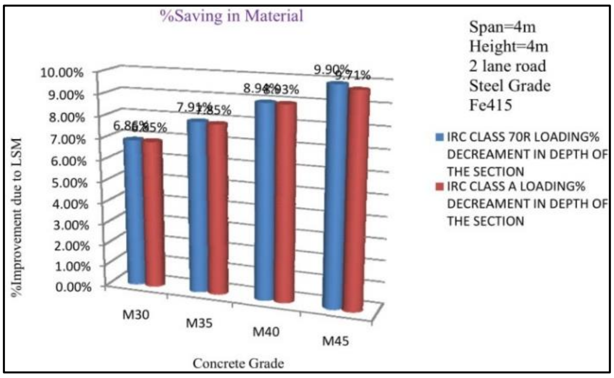

Fig. 7.2: Saving in Material using LSM Approach over WSM for Fe415 Steel Grade

Fe500	IRC CLASS 70R LOADING	IRC CLASS A LOADING
CONCRETE GRADE	% DECREAMENT IN DEPTH OF THE SECTION	% DECREAMENT IN DEPTH OF THE SECTION
M30	6.82%	6.74%
M35	7.87%	7.65%
M40	8.89%	8.55%
M45	9.70%	9.42%

Table 7.4: Saving in Material using LSM Approach over WSM for Fe500 Steel Grade

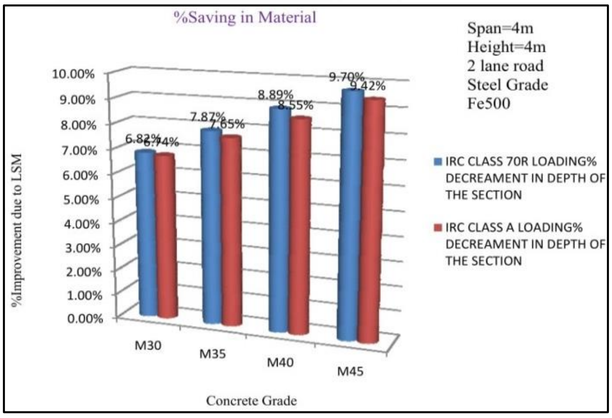

Fig. 7.3: Saving in Material using LSM Approach over WSM for Fe500 Steel Grade

B. Discussion

1) There will be three conditions for analysis and designing of Box Culvert (I) Box Empty (II) Box Full with Live Load and (III) Box Full without Live Load.
2) The water pressure is the only load that produces the moment in the opposite directions on the side walls i.e. counteracting moments.
3) Box empty condition is the critical load combination because all loads produces the moment in the same directions with no counter balancing from water pressure. This shall make worst condition of analysis and design of box culvert.
4) Keeping the section constant 6-10% saving in steel can be obtained by shifting from WSM to LSM design approach.
5) For constant steel area, section of top, wall and bottom can be reduced by 7-12% if design is done by LSM approach instead of WSM approach.
6) At higher grade of concrete more saving in steel is observed.
7) Formulas that are used in LSM design are simple to apply and there is separate partial safety factor for both concrete and steel reinforcement.
8) There are two limits in LSM approach (I) Limit State of Collapse & (II) Limit State of Serviceability. Limit State of Collapse corresponds to the Flexure, Compression, Shear, and Torsion while Limit State of Serviceability corresponds to Deflection, Cracking, Corrosion and Excessive Vibration. These limits are based on the various probabilities and because of this LSM approach is also called as Probabilistic Approach. These make LSM approach is farther better than the WSM approach.

VIII. Conclusions

In the present study on "Analysis & Design of RCC Box Culvert using WSM & LSM" the analysis & design of box culvert under different loading conditions has been carried out. A sample problem of 4M span with Empty Box Condition is analysed by manual and STAAD Pro software. The design for the same is carried out with conventional WSM approach & as per latest guidelines of IRC: 6 – 2014 using LSM approach. A MS – Excel tool is developed for analysis and design of box culvert. The tool is capable of analyzing box culvert for all three possible situations i.e. (I) Case-1 Box Empty (II) Case-2 Box Full (With Live load) & (III) Case-3 Box Full (Without Live Load) and box culvert subjected to 2 types of loading i.e. (I) IRC Class 70R Loading & (II) IRC Class A Loading. With the develop tool design can be carried out using WSM as well as LSM approaches.
The results from the develop tool analysis & design are compared with manual & STAAD Pro analysis/calculation. From the study following conclusions may be drawn:

1) The develop MS – Excel tool for analysis & design of box culvert is accurate, fast, easy to use & user friendly application.
2) No software and additional knowledge to run software is required for the analysis and design of box culvert.
3) Empty box culvert condition is found to be most critical loading combination as in this case no counterbalancing moments are available because of non-availability of water head.

Although IRC Class 70R Loading are higher as compared to IRC Class A Loading but due to higher impact factor in case of IRC Class A Loading sometimes shear check becomes critical.

From the parametric study it is observed that for a constant section, a saving of tune of 6-10% may be achieved by using LSM approach, amount of saving is higher for higher grades of concrete.

From the parametric study, it is also observed that for a constant Steel Area a saving of the tune of 7-12% may be attained in concrete by using LSM approach over WSM design approach. For higher grades of concrete saving is higher.

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