PARAMETRIC STUDY ON BEHAVIOUR OF RCC BOX CULVERT FOR DYNAMIC LOADING

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Abstract: *Structural analysis is a process to analyse a structural system in order to predict the responses of the real structure under the action of expected loading and external environment during the service life of the structure. The present work reflects on the analysis and design of bridges which are the main source of human life which helps to travel from place to place. The modeling and analysis of bridge is carried out by using the software Staad-pro software. The bridge we designed is box culvert bridge. The design loads are considered as per IRC 6. Box culvert is designed by using Staad-pro and results are compared manually.*

Keywords: box culvert, coefficient of earth pressure, lateral earth pressure, pavements, single cell, multiple cells, earth embankment, etc

1. INTRODUCTION

Box culverts are the structures constructed below highways and railways to provide access to the natural drainage across them. They are also constructed sometimes to provide the access to the animals to cross the road.

Culverts are the structures constructed across the drainages below the highway and railways for easy access for animals and humans. The dimensions of culvert are designed based on waterway. Thickness is adopted based on loads acting on culvert and span of culvert.

STAAD.Pro 2006 is a suite of proprietary computer programs of Research Engineers, a Bentley Solutions Center. Although every effort has been made to ensure the correctness of these programs, REI will not accept responsibility for any mistake, error or misrepresentation in or as a result of the usage of these programs. STAAD.Pro is a general purpose structural analysis and design program with applications primarily in the building industry - commercial buildings, bridges and highway structures, industrial structures, chemical plant structures.

2. METHODOLOGY

The structure is designed like rigid frame using moment distribution method to obtain final moments on the basis of their relative stiffness of the slab and side walls. A few things like depth of cushion, coefficient of earth pressure for lateral pressure on walls, width or angle of dispersion for live loads on box culvert without cushion and with cushion are taken into consideration.

A. Effective width in the run of culvert: The IRC:21-20006 Clause 305.16 gives an equation for obtaining effective width for simply supported and continuous slab for different ratio of overall width verses span for these two kinds of supports. bef= $\alpha x\left(1-\frac{x}{l}\right)+bw$,bef = effective width of slab on which load acts. l = effective span. x = distance of the centre of gravity of the concentrated load from the nearer support.bw = breadth of concentration area of the load. α = constant having the following values depending upon ratio b/l.

B. Braking force / Longitudinal force: These forces result from vehicles braking or accelerating while travelling on a bridge. At a vehicle brakes, load of the vehicle is transferred from its wheels to the bridge deck. The IRC specifies a longitudinal force of 20% of the appropriate lane load. This height generally is taken to be 3m. Thus no braking force for cushion height of 3 m and more and full braking force for no cushion, for intermediate heights of cushion the braking force can be interpolated. IRC: 6-2000 Clause 211.7 mentions that no effect to be taken at 3 m below bed block in case of bridge pear/abutment.

C. Impact of live load: In order to account for the dynamic effects of the sudden loadings of a vehicle on to a bridge structures, an impact factor is to used as a multiplier for loads on certain structural elements. From basic dynamics we know that a load that moves across a member introduces larger stresses than those caused by a standstill load. However the basis of impact factor predicted by IRC is not fully known. It has been felt by researchers that the impact factor to a large extent depends on weight of the vehicle, its velocity, as well as surface characteristics of the road. IRC specifications for impact factor are computed as mentioned below:

For class AA loading.

a) For spans less than 9m:

1. For tracked vehicles:25% for spans up to 5m linear reducing to 10% for spans of 9m.

2. For wheeled vehicles:25% Appropriate impact factors as mentioned below need to be considered for substructures as well:

- At the bottom of the bed block: 0.5
- For the top 3m of the substructure: 0.5 – 0.0
- For the portion of the substructure > 3m below the block: 0.0

Modeling and analysis of box is done by STAAD pro software.

Foundations are designed based on the subsoil strata and properties of soil.

It includes

1. Collection of existing Nala details

2. Soil testing

3. Discharge calculations

4. Hydraulic calculations

The box culvert should be designed for the following cases

Case1) When the top slab carries the dead load and live load and the culvert is empty.

Case2) When the top slab carries the dead load and live load and the culvert is full of water.

Case3) When the top slab do not carries live load and the culvert is full of water.

2.1HYDRAULIC CALCULATIONS OF BOX CULVERT

2.1.1Hydraulic data:

Catchment area(M) = 24.5Sq KM

Skew (a) = 30^0

Nala bed level(NBL) = 533.254m

Raft/sill level = 532.954m

High flood level(HFL)= 535.754m

Ryve's Co efficient©= 10.50

2.1.2Soil data:

Type of soil 3.00 mtr BC soil followed by ordinary slushy type

Safe bearing capacity of soil (SBC) 8.5t/sqm=83.385KN/sqm

Unit weight of soil = 1.8t/cum m= 17.658KN/cum m

Depth of soil = 3 m

Silt factor(f) = 1.25

2.1.3Nala particulars:

Bed slope of nala =0.196/100=0.00196=1:510.2

Manning's coefficient (n)= 0.035

2.1.4Discharge calculations:

Discharge calculation by Ryve's formula:

The flood discharge is calculated based on catchment area by Revy's method.

Discharge (Q)= $C * M^{\frac{2}{3}}$

Q = 88.573 cumecs say 90cumecs

Discharge calculation by Area velocity method:

The flood discharge is calculated based on Area velocity method and area is calculated by using details of cross section of Nala.

Area (A)= 61.32sqm

Wetted perimeter (P)= 43.24m

Hydraulic mean depth (R)= $\frac{A}{P}$= 1.418m

Velocity based on manning's formula (V)= $\frac{1}{n} * R^{\frac{2}{3}} * S^{\frac{1}{2}}$= 1.599m/sec

Discharge (Q)=$A * V$= 98.02cumecs

2.1.5 Hydraulic data for design

As per IRC:SP:13-2004, the recommended rule to estimate the design discharge is maximum of these two calculated value, provided it should not exceed next maximum discharge by 50%, if it exceeds then restrict it to limit required.

Discharge calculation by Ryve's formula= 90cumecs

Discharge calculation by Area velocity method = 100cumecs

Maximum discharge adopted = 100cumecs

HFL =535.754m

Sill/raft level = 532.954m

Discharge per m width(Qm)=2.5cumecs/m

2.1.6 Box details(span arrangement of box culvert)

Maximum discharge adopted = 100cumecs

Max. depth of flow=3m

Depth of box=3+09=3.9m

So therefore provide depth of box=4m

Assume width of box =6m

Span arrangement of box culvert is 6m*4m

Total length of bridge =44.64m

No. of box to be provide=44.64/6=7.44nos

So provide 6 no of cells

No. of groups provided=3

No. of cells in each group=2

Designed linear water way=6*6=36m

Earth cushion=0

Thickness of slab and walls are normally taken as 1/10th to 1/15th of total span, from design of bridge structures M A Jayram.

Depth of the slab=0.45m

Depth of bottom slab=0.45m

Depth of vertical slab=0.45m

Table.NO 1. From IRC SP 13-2004 PNO 37 provide free board

Discharge(cumecs)	freeboard(m)
0.300	0.150
0.3- 3	0.450
3-30	0.450
30-300	0.900
300-3000	1.200
3000.000	1.500

2.1.7 Vent way calculations

Regime's width as per Lacey's formula W = C*Q^(1/2)

C=4.8

Regime width=100^(1/2)*4.8=48m

Regime width > Linear water way

The linear water way provided is more than Regime width of the stream

2.1.8 Scour depth calculations

(As per cl. 703 of IRC:78-2000 given in IRC:SP:13-2004 P No 27)

Normal scour depth dsm=1.34*(Qm^2/f)^1/3=2.3m

f Lacey's silt factor=1.25

Therefore Normal scour depth dsm=2.3m

The bottom slab top level of box is kept 0.30m below the lowest nala bed level

The bottom slab level is= NBL-0.30=533.254-0.30 =532.954

2.1.9 Apron details

As per IRC:SP: 13-2004

Length of D/S Apron= 2 times of normal scour depth=4.5m

Length of U/S Apron= 1.5 times normal scour depth=3.5m=4m

2.1.10 Afflux Calculation

As per moles Worth formula=[V^2/17.88+1/65.60]×{[A/a]^2-1} Here unobstructed waterway and clear water way are similar hence afflux is zero.

2.2 Design of box culvert

For our design considering 1m length of box culvert is considered and analysis is done for three loading cases.The box culvert dimensions to be considered are 4*6m and take wearing coat thickness as 80mm. The analysis of box culvert is done by considering the center line of frame structure of box culvert. As it has 6 cells and dividing these cells to 2 groups each contains 3cells of box. For easy analysis we consider one cell as all these cells are similar then we can use these values for other boxes too. As load on all boxes are same.

2.2.1 Case 1) When the top slab carries the dead load and live load and the culvert is empty.

Concentrated vertical load is acting as wheel load W=PI/bef

Where P is wheel load

I is impact factor

bef is effective width of depression

effective width of depression for wheel load from P.NO 53 IRC 21

$$\text{bef}= \alpha x\left(1-\frac{x}{l}\right)+bw$$

here B=7.5m l=6.45 and B/l=7.5/6.45=1.162 , $\alpha = 2.625$, $x = \frac{6.45}{2} = 3.225$

bef=2.625*3.225(13.225/4.45)+0.85+2*.08=5.24m

net effective width of dispersion =1.2+.425+2.05+5.24/2=6.30m

effective length of dispersion = 3.6+2(0.45+0.08)=4.66m

This length is greater than actual span hence intensity of loading needs to be reduced proportionately.

Reduced load = 700*4.45/4.66=668.455KN

Load with impact effect = 1.25*668.455=835.57KN

Intensity of live load on the slab=835.57/4.45*6.30=29.80 Say 30KN/m^2=30000N/m^2

2.2.1.1Load and reactions:

1. Top load calculation

a. Weight of top slab= 25*0.45*1=11.25 KN/m^2

b. Super imposed dead load=0 KN/m^2

c. Live load= 30 KN/m^2

d. Total load on top slab=11.25+30= 41.25 KN/m^2

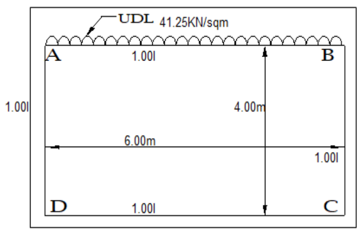

Fig. NO 1. Box details

2. Weight of two vertical wall calculation

a. Weight of two vertical walls = 2*25*0.45*4.45= 100.125 KN/m^2

b. Vertical wall height=4+(0.45/2)+(0.45/2)= 4.45m

3. Bottom load calculation

a. Intensity of pressure on base slab =((41.25*6.45)+100.125)/6.45= 56.77 KN/m^2

b. Effective width of top slab =6+(0.45/2)+(0.45/2)=6.45 m

4. Lateral loads at top and bottom of vertical wall due to top slab

Coefficient of active earth pressure is=$\frac{1-sin\theta}{1+sin\theta} = \frac{1-sin30}{1+sin30}=\frac{1}{3}$

a. at top of deck h=0 p=(0+30)/3= 10 KN/m^2

b. at bottom of deck h=4.45m

p=(0+30)+(18*4.45)/3= 36.7 KN/m^2

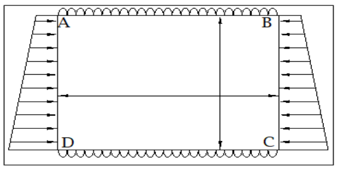

Fig. NO 2. Loading details

2.2.2Case 2: When the top slab carries the dead load, live load and the culvert is full of water.

2.2.2.11Load and reactions:

1. Top load calculation

Weight of top slab =25 *0.45*1 =11.25KN/m^2

Super imposed dead load=0 KN/m^2

Live load= 30 KN/m^2

Total load on top slab =11.25+30= 41.25 KN/m^2

2. Weight of two vertical wall calculation Weight of two vertical walls=2*25*0.45*4.45= 100.125 KN/m^2

Vertical wall height=4+(0.45/2)+(0.45/2)= 4.45 m

3. Bottom load calculation

Intensity of pressure on base slab=((41.25*6.45)+100.125)/6.45= 56.77 KN/m^2

Effective width of slab=6+(0.45/2)+(0.45/2)=6.45 m

4. Lateral loads at top and bottom of vertical wall due to top slab

Coefficient of active earth pressure is=$\frac{1-sin\theta}{1+sin\theta} = \frac{1-sin30}{1+sin30}=\frac{1}{3}$

a.at top of deck h=0 p=(0+30)/3= 10 KN/m^2

b.at bottom of deck h=4.45m

p=(0+30)+(18*4.45)/3= 36.7 KN/m^2

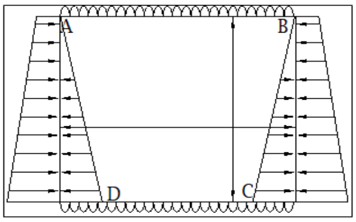

Fig.NO.3- Loading details

2.2.3 Load case 3: When the top slab carries the only dead load and the culvert is full of water.

2.2.3.1Load and reactions:

1. Top load calculation

a. Weight of top slab= 25*0.45*1= 11.25KN/m^2

b. Super imposed dead load=0 KN/m^2

c. Live load= 0 KN/m^2

d. Total load on top slab=11.25+0= 11.25 KN/m^2

2. Weight of two vertical wall calculation

a. Weight of two vertical walls=2*25*0.45*4.45= 100.125 KN/m^2

b. Vertical wall height=4+(0.45/2)+(0.45/2)= 4.45 m

3. Bottom slab load calculation

a. Intensity of pressure on base slab=((41.25*6.45)+100.125)/6.45= 56.77 KN/m^2

b. Effective width of top slab=6+(0.45/2)+(0.45/2)=6.45 m

c. Lateral loads at top and bottom of vertical wall due to top slab

Coefficient of active earth pressure is=$\frac{1-sin\theta}{1+sin\theta} = \frac{1-sin30}{1+sin30}=\frac{1}{3}$

a.at top of deck h=0 p=(0+30)/3= 10 KN/m^2

b.at bottom of deck h=4.45m

p=(0+30)+(18*4.45)/3= 36.7 KN/m^2

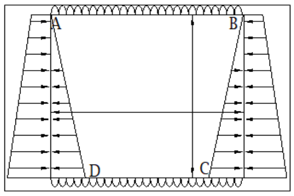

Fig.NO.4. Loading detail

2.3 Modeling and design of box culvert using staad-pro

1. STEP 1: Opening of new project and selecting of dimension units.
2. STEP 2: Arrangements of grids as per dimension of box culvert.
3. STEP 3: Drawing of box culvert as per diagram(placing of nodes and joining them as per diagram)
4. STEP 4: Placing of sections(beams, columns and slab)
5. STEP 5: Placing of support reactions.
6. STEP 6: Adding of loads and applying loads to box culvert.
7. STEP 7: Checking for errors.
8. STEP 8: Analyzing of the box culvert

Load case1:

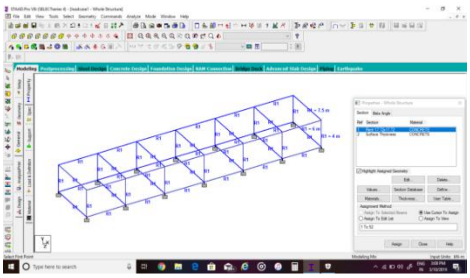

Fig.NO.5. Surface property

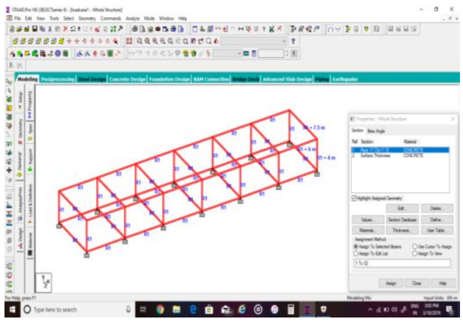

Fig.NO.6. Section property

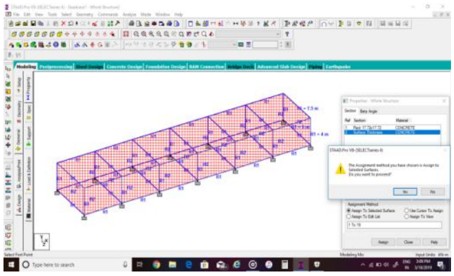

Fig.NO.7. Model property

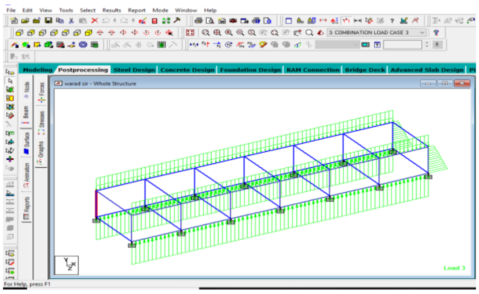

Fig.NO.8. Loading property

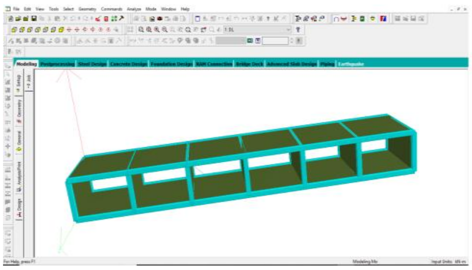

Fig.NO.9. 3-D Model of box culvert

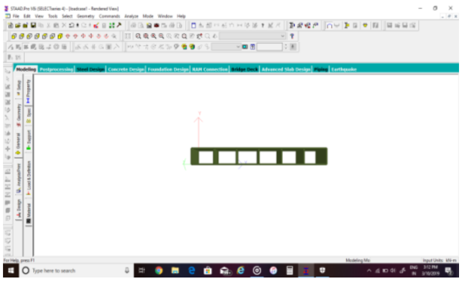

Fig.NO.10. Opening of Boxes

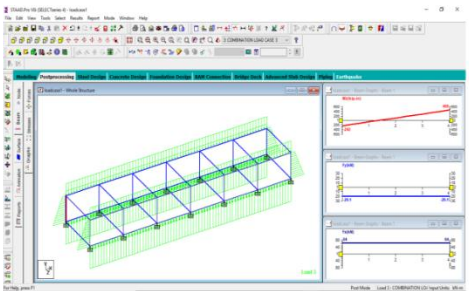

Fig.NO.11. Results and Graphs

Load case 2

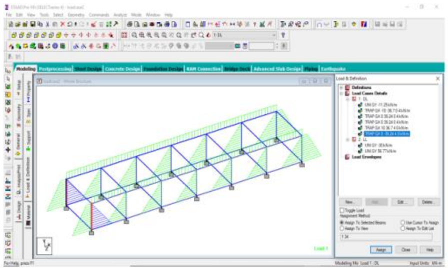

Fig.NO.12. Loading property

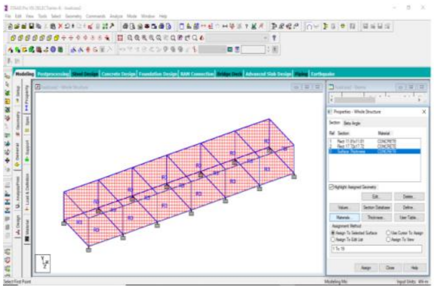

Fig.NO.13. Model property

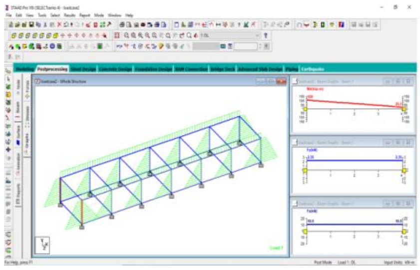

Fig.NO.14. Results and Graphs

Load case 3:

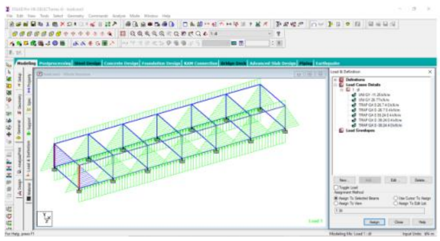

Fig.NO.15. Loading property

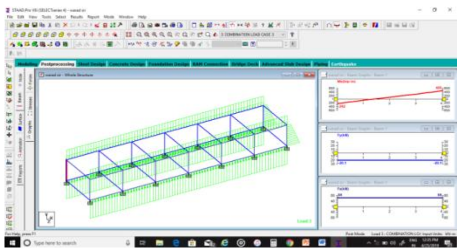

Fig.NO.16. Results and Graph

2.4 Results and its comparison

Empty box condition is found to be most critical loading combination as in this case no counter balancing moments are available because of non-availability of water head.

2.5Comparison of results

Table NO.2. Comparison of results for different load cases

LOAD CASES	BENDING MOMENT(KN-M)					
	TOP SLAB		BOTTOM SLAB		SIDE WALLS	
	STAAD	MANUAL	STAAD	MANUAL	STAAD	MANUAL
1	276.53	214.612	386.73	294.86	197.65	148.195
2	264.68	214.513	264.68	214.513	169.78	69.33
3	166.82	58.51	238.56	138.84	86.53	20.978

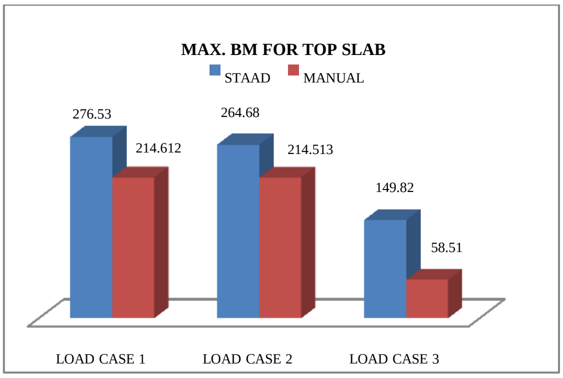

Fig.NO.20.Comparision of top slab result

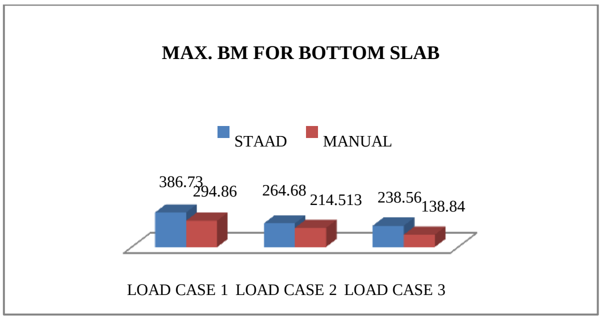

Fig.NO.21.Comparision of bottom slab result

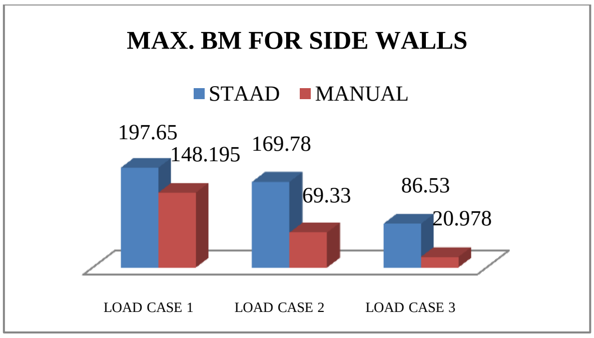

Fig.NO.22.Comparision of side wall result

Table NO.3. Shear force values

LOAD CASES	SHEAR FORCE (KN)					
	TOP SLAB		BOTTOM SLAB		SIDE WALLS	
	STAAD	MANUAL	STAAD	MANUAL	STAAD	MANUAL
1	175.68	133.0313	257.31	183.083	154.63	110.3711
2	175.68	133.313	257.31	183.083	85.63	25.53002
3	116.36	36.28125	257.31	183.083	196.76	88.12113

2.6Reinforcement details

Table NO.4. Comparison of results for Reinforcement

Details	Type of beam	SOFTWARE (mm^2)	MANUAL(mm^2)
Reinforcement	Top slab	1683.33	1284.80
	Bottom slab	2433.03	1804.80
	Side wall	1177.96	872.078

2.7 DISCUSSIONS:

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.

3. CONCLUSIONS

1. Hydrological structures are complicated to design as it requires various surveys before execution of work.
2. For load case 1 Bending moment value of top slab is increased by 22% bottom slab by 23% and side walls by 25% in STAAD-PRO when compared with manual calculation.
3. For load case 2 Bending moment value of top slab is increased by 18% bottom slab by 18% and side walls by 25% in STAAD-PRO when compared with manual calculation.
4. For load case 3 Bending moment value of top slab is increased by 21% bottom slab by 18% and side walls by 23% in STAAD-PRO when compared with manual calculation.
5. For load case 1 Shear force value of top slab is increased by 24% bottom slab by 27% and side walls by 28.9% in STAAD-PRO when compared with manual calculation.
6. For load case 2 Shear force value of top slab is increased by 24% bottom slab by 27% and

side walls by 29% in STAAD-PRO when compared with manual calculation.
7. For load case 3 Shear force value of top slab is increased by 33% bottom slab by 27% and side walls by 55% in STAAD-PRO when compared with manual calculation.
8. Reinforcement for top slab is increased by 24% bottom slab by 25% and side wall by 26% in STAAD-PRO when compared with manual calculation.

4. REFERENCES

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