COMPARATIVE STUDY ON STRUCTURAL MODELING, SIMULATION AND ANALYTICAL DESIGN OF REINFORCED CONCRETE TRIPLE BOX CULVERT USING STAADPRO AND SPREADSHEET

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Abstract

Culvert is hydraulic structure that is used to convey and discharge water as part of drainage system. Many roads are damaged by floods consequent upon unavailability or inefficient drainage system which claim many lives and properties. In designing culvert, the analysis and design especially multiple cell-boxes is painstaking. Due to the cumbersome analysis of culvert, several structural engineering softwares are developed and used for the analysis and design of culverts such as spreadsheet. However, there is no RCC spread sheet written and developed that can be used for analysis and design of multi box culvert which will make design simplier and faster on the field and in the design office. The comparative analysis and design of multi box culvert using Staadpro and Spreadsheet is undertaken in this research. The result produced by staadpro is not as reliable as that of spreadsheet in term of analysis. In conclusion, it is reliable to develop program as an engineer such as spreadsheet, MATLAB, C++, ABAQUS, ARDENAL e.t.c to solve engineering problem because most of the sofwares come with definite program and assumption which are sometimes not clear to engineer.

Keywords: culvert, floods, analysis, design, staadpro, spreadsheet

Introduction

Culvert is defined as a tunnel or buried structure constructed under roadways or railways to provide cross drainage or take electrical cables from one side to other. It is totally enclosed by soil or ground. The design of culvert is based on hydrological properties which are intensity of rainfall (i), duration of rainfall (t), frequency of rainfall, catchment area (A) and hydraulic properties of flow such as flow rate (Q), velocity of flow (V) and cross sectional area of culvert which determine its size.

Fig 1: Coming full circle (http://oregonewrg.org/wp-content/uploads/2015/12/Sheean-Culvert-Presentation.pdf)

The positioning of culverts across a water body is dependent on economy and uses. The three main factors of design are safety, intended use of structure and economy but safety is most important factor to be considered in design of structures (BS 8110-1, 1997). The earliest empirical methods advocated for oversized designs is that size must be proportional to the greatest quantity of water which can ever be required to pass and should be large enough to admit a boy to enter to clean them out (see Fig.1). The empirical methods enunciated in Dun's table in the 1900s, became slightly more sophisticated with no hydraulic considerations. Away from traditional software designing multiple cells culvert there is need for more user friendly, reliable and easy means of designing such culvert and even serve as tool for engineering design if such projects comes.

Table 1: Dun Drainage Table

Table 1
The Dun Drainage Table
Atchison, Topeka & Santa Fe Railway System (1906)

Areas Drained in Square Miles	Areas of Waterway: Missouri and Kansas	Cast Pipe. Banks over 15 Ft. Use 80 Per Cent	Box and Arch Culverts. 1st Fig. Diam. 2d. Fig. Bench	Percentage of Column 2: Illinois	Indian Territory	Texas	New Mexico
1	2	3	4	5	6	7	8
.01	2.0	1-24 in.	2 x1 B				
.02	4.0	1-24 "	2 x2 "				
.03	6.0	1-30 "	2 x3 "				
.04	7.5	1-36 "	2½x3 "				
.05	9.0	1-42 "	3 x3 "	East of	South of	Use	Use
.06	10.5	1-42 "	3½x3 "	Streator	Purcell	Column	Column
.07	12.0	1-48 "	3 x4 "	use 60	use Texas	2	2
.08	13.5	2-36 "	2½x3 "	per cent	Column		
.09	15	2-36 "	2½x3 "				
.10	16	2-36 "	3 x3 "				
.15	25	2-48 "	3 x4 "				
.20	32	3-42 "	6 x4 A				

Areas Drained in Square Miles	Areas of Waterway: Missouri and Kansas	Percentage of Column 2: Illinois	Indian Territory	Texas	New Mexico
1	2	5	6	7	8
24	1,060			110	94
26	1,100			110	92
28	1,140			110	92
30	1,180			110	92
32	1,220	East of	South of	110	92
34	1,255	Streator	Purcell	110	92
36	1,290	use 60	use Texas	110	91
38	1,320	per cent	Column	110	91
40	1,350			110	91
45	1,435			110	91
50	1,510			110	89½
55	1,580			115	89½

James Dun, 1906

Rational method was formulated and described by Irish engineer (T.Mulvaney,1851) .Though, he considered the hydraulics but no inlet/outlet control was included. The method was not widely accepted until much more later.In 1926, ground breaking research introduced modern culvert hydraulics by Bureau of Public Roads and University of Iowa called corrugated metal pipe design which paid more attention to roughness coefficient and inlet/ outlet control unlike rational method (D E. Metzler & H .Rouse) Also in 2013, Water Crossing Design Guidelines measure the channel width, the watershed, its area and rainfall, its vegetation and substrate. Thus the channel width acts as a surrogate for the hydraulic analysis.

Methodology

The analysis and design of a 3-cell culvert were undertaken with the Staadpro and Excel spreadsheet program and the results were compared.

The procedure followed for structural design of triple box culvert are as enunciated below:

1. Estimate total load on top slab which includes weight of earth fill, axle load of vehicle and self-weight of top slab.
2. Determine total load on wall which include total load on top slab and self-weight of wall
3. Determine total load on bottom slab which include total load on wall and self-weight of bottom slab.
4. Moment distribution method was used to analyse the culvert to determine the shear force , bending moments (support moments and span moments)
5. Span reinforcement and support reinforcement were designed.

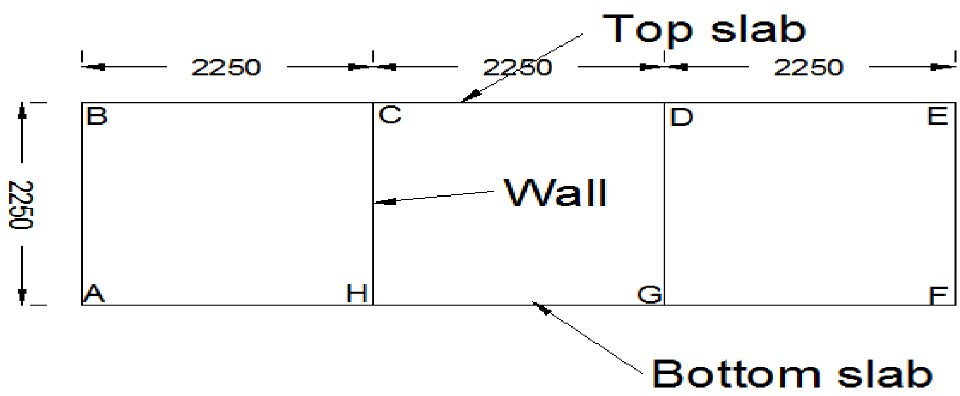


Fig.2 Triple box Culvert

Result Analysis

Loading and Structural Analysis Formulae

Self weight of top and bottom slab = □f_1*□c*thickness of slab

Earth pressure at the top of wall

$P_t = K_a$* □f_2*□s*h_1

Earth pressure at the top of wall

$P_b = K_a$* □f2*□s*h_2

Axle wheel load = $W/4h^2$

Fixed end moment (M^F) = +_ $Wl^2/12$ for uniformly distributed load

Fixed end Moment (M^F) = +_ $Wl^2/12$+_$Wl^2/20$(Linearly Varying load)

Fixed end Moment (M^F) = +_ $Wl^2/12$+_$Wl^2/30$(Linearly Varying load)

Maximum span moment occurs where **$\partial M/\partial x = 0$**

Statics shear force **(V_S) = wl/2**

Dynamic shear force **(V_{dm}) = /M_1 /- /M_2//L**

$V = V_S + V_{dm}$

Table 2: SPREADSHEET FOR STRUCTURAL ANALYSIS AND DESIGN OF TRIPLE BOX CULVERT

Loading

REFERENCES			CALCULATIONS	OUTPUT	UNITS
BS 5400 part 2, table 1	Dead load				
	design parameters;				
	?f1(Self weight of culvert)	1.15			
	?f2 (earth fill)	1.5			
	?f3 (HA vehicle)	1.5			
	Unit weight of concrete	24			KN/m3
	Unit weight of soil	18			KN/m3
	Top slab	300			mm
	bottom slab	300			mm
	walls	250			mm
	No of cell walls	4			
	Height of walls	2250			mm
	Height of fill	1000			mm
	Span of culvert	6750			mm
	For 300mm top slab		8.28	8.28	KN/m2
	For300mm base slab		8.28	8.28	KN/m2
	For 250mm cell walls		9.20	9.20	KN/m2
	For weight of fill		27.00	27.00	KN/m2
	Total dead load		52.76	52.76	KN/m2
	span of each box	2250			mm
	Width (B)	1000			mm

.

REFERENCES		CALCULATIONS	OUTPUT	REMARK
	Analysis of forces			
	Total bending pressure on members			
Members				
Top slab		167.63	KN/m2	
bottom slab		185.11	KN/m2	
Earth pressure at the top of wall		62.12	KN/m2	
Earth pressure at the bottom of wall		82.37	KN/m2	
		20.25	KN/m2	
FEM				
MF AB		-31.33	KNm	
MF BA		29.62	KNm	
MF BC		-70.72	KNm	
MF CB		70.72	KNm	
MF CH		0.00	KNm	
MF CD		-70.72	KNm	
MF DC		70.72	KNm	
MF DG		0.00	KNm	
MF DE		-70.72	KNm	
MF ED		70.72	KNm	
MF EF		-29.62	KNm	
MF FE		31.33	KNm	
MF FG		-78.09	KNm	
MF GF		78.09	KNm	
MF GD		0.00	KNm	
MF GH		-78.09	KNm	
MF HG		78.09	KNm	
MF HA		-78.09	KNm	
MF AH		78.09	KNm	
MF HC		0.00	KNm	
Moment of inertia				
Itop	0.00225		m3	
Ibottom	0.00225		m3	
Iwall	0.001302083		m3	
Stiffness ratio				
ktop	0.000000001			
kbottom	0.000000001			
kwall	5.78704E-10			
Distribution factor				
DFAB	0.366568915	0.37		
DFAH	0.633431085	0.63		
DF BC	0.633431085	0.63		
DF BA	0.366568915	0.37		
DF CB	0.387791741	0.39		
DF CD	0.387791741	0.39		
DF CH	0.224416517	0.22		
DF DC	0.387791741	0.39		
DF DE	0.387791741	0.39		
DF DG	0.224416517	0.22		
DF ED	0.366568915	0.37		
DF EF	0.633431085	0.63		
DF FE	0.366568915	0.37		
DF FG	0.633431085	0.63		
DF GF	0.387791741	0.39		
DF GH	0.387791741	0.39		
DF GD	0.224416517	0.22		
DF HG	0.387791741	0.39		

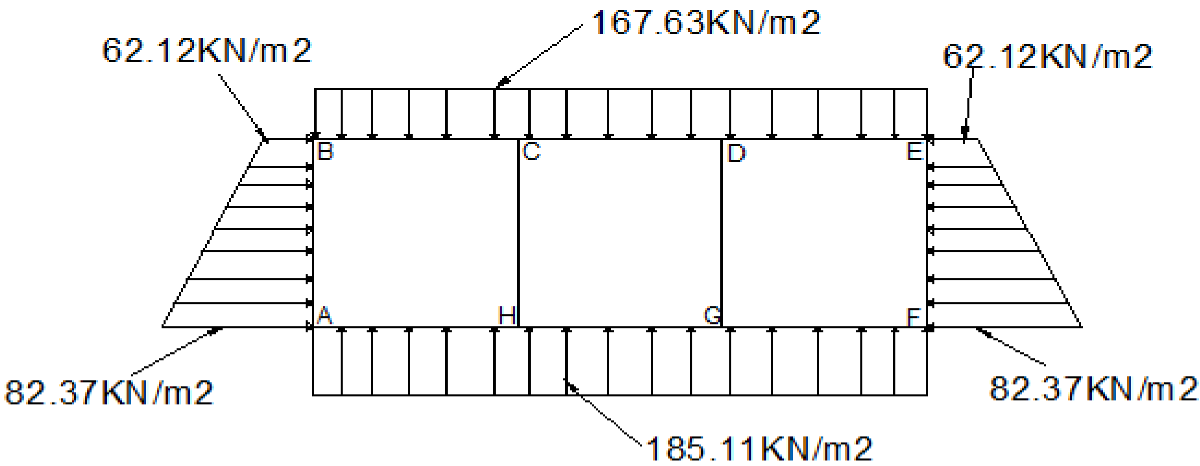


Fig. 3: Load arrangement on culvert

Table 3: STRUCTURAL ANALYSIS (SPREADSHEET FOR MOMENT DISTRIBUTION OF TRIPLE BOX CULVERT)

JT	A		B		C			D			E		F		G			H		
MEM	AH	AB	BA	BC	CB	CD	CH	DC	DE	DG	ED	EF	FE	FG	GF	GH	GD	HG	HC	HA
DF	0.63	0.37	0.37	0.63	0.39	0.39	0.50	0.39	0.39	0.50	0.37	0.63	0.37	0.63	0.39	0.39	0.22	0.39	0.22	0.39
MF	78.09	-31.33	29.62	-70.72	70.72	-70.72	0.00	70.72	-70.72	0.00	70.72	-29.62	31.33	-78.09	78.09	-78.09	0.00	78.09	0.00	-78.09
BM	-46.76		41.10		0.00			0.00			-41.10		46.76		0.00			0.00		
DM	-29.62	-17.14	15.06	26.03	0.00	0.00	0.00	0.00	0.00	0.00	-15.06	-26.03	17.14	29.62	0.00	0.00	0.00	0.00	0.00	0.00
COM	0.00	7.53	-8.57	0.00	13.02	0.00	0.00	0.00	-7.53	0.00	0.00	8.57	-10.41	0.00	14.81	0.00	0.00	0.00	0.00	-14.81
BM	-7.53		8.57		-13.02			7.53			-8.57		10.41		-14.81			14.81		
DM	-4.77	-2.76	3.14	5.43	-5.05	-5.05	-6.51	2.92	2.92	3.77	-3.14	-5.43	3.82	6.60	-5.74	-5.74	-3.32	5.74	3.32	5.74
COM	2.87	1.57	-1.38	-2.52	2.71	1.46	1.66	-2.52	-1.57	-1.66	1.46	1.91	-2.71	-2.87	3.30	2.87	1.88	-2.87	-3.25	-2.39
BM	-4.44		3.90		-5.84			5.76			-3.37		5.59		-8.05			8.51		
DM	-2.81	-1.63	1.43	2.47	-2.26	-2.26	-2.92	2.23	2.23	2.88	-1.23	-2.13	2.05	3.54	-3.12	-3.12	-1.81	3.30	1.91	3.30
COM	1.65	0.72	-0.81	-1.13	1.24	1.12	0.96	-1.13	-0.62	-0.90	1.12	1.02	-1.07	-1.56	1.77	1.65	1.44	-1.56	-1.46	-1.41
BM	-2.37		1.95		-3.31			2.65			-2.14		2.63		-4.86			4.43		
DM	-1.50	-0.87	0.71	1.23	-1.28	-1.28	-1.65	1.03	1.03	1.33	-0.78	-1.36	0.96	1.66	-1.88	-1.88	-1.09	1.72	0.99	1.72
COM	0.86	0.36	-0.43	-0.64	0.62	0.51	0.50	-0.64	-0.39	-0.55	0.51	0.48	-0.68	-0.94	0.83	0.86	0.66	-0.94	-0.83	-0.43
BM	-1.22		1.07		-1.63			1.58			-1.00		1.62		-2.35			2.20		
DM	-0.77	-0.45	0.39	0.68	-0.63	-0.63	-0.81	0.61	0.61	0.79	-0.37	-0.63	0.59	1.03	-0.91	-0.91	-0.53	0.85	0.49	0.85
COM	0.43	0.20	-0.22	-0.32	0.34	0.31	0.25	-0.32	-0.18	-0.26	0.31	0.30	-0.32	-0.46	0.51	0.43	0.39	-0.46	-0.41	-0.38
BM	-0.62		0.54		-0.89			0.76			-0.60		0.77		-1.33			1.25		
DM	-0.40	-0.23	0.20	0.34	-0.35	-0.35	-0.45	0.30	0.30	0.38	-0.22	-0.38	0.28	0.49	-0.52	-0.52	-0.30	0.48	0.28	0.48
COM	0.24	0.10	-0.11	-0.17	0.17	0.15	0.14	-0.17	-0.11	-0.15	0.15	0.14	-0.19	-0.26	0.24	0.24	0.19	-0.26	-0.22	-0.20
BM	-0.34		0.29		-0.46			0.43			-0.29		0.45		-0.68			0.68		
DM	-0.22	-0.12	0.11	0.18	-0.18	-0.18	-0.23	0.17	0.17	0.22	-0.11	-0.18	0.16	0.28	-0.26	-0.26	-0.15	0.26	0.15	0.26
COM	0.13	0.05	-0.06	-0.09	0.09	0.08	0.08	-0.09	-0.05	-0.08	0.08	0.08	-0.09	-0.13	0.14	0.13	0.11	-0.13	-0.11	-0.11
BM	-0.18		0.15		-0.25			0.22			-0.17		0.22		-0.38			0.35		
DM	-0.12	-0.07	0.06	0.10	-0.10	-0.10	-0.13	0.08	0.08	0.11	-0.06	-0.11	0.08	0.14	-0.15	-0.15	-0.09	0.14	0.08	0.14
EM	44.07	-44.07	39.13	-39.13	79.06	-76.93	-9.12	73.18	-73.83	5.87	53.37	-53.37	40.95	-40.95	87.11	-84.50	-2.61	84.37	0.95	-85.32
SM	135.88		43.25	126.99		107.96	0.00		116.55	0.00		52.82		141.35		116.55	0.00		0.00	
Vs	208.24	85.07	77.47	188.58	188.58	188.58	0.00	188.58	188.58	0.00	188.58	77.47	85.07	208.24	208.24	208.24	0.00	208.24	0.00	208.24
Vdm	-18.33	2.20	-2.20	-17.75	17.75	1.67	3.63	-1.67	9.10	1.45	-9.10	5.52	-5.52	-20.51	20.51	0.06	-1.45	-0.06	-3.63	18.33
V	189.91	87.27	75.28	170.83	206.33	190.25	3.63	186.91	197.67	1.45	179.48	82.99	79.55	187.73	228.76	208.30	-1.45	208.19	-3.63	226.58

Result Analysis from Staadpro

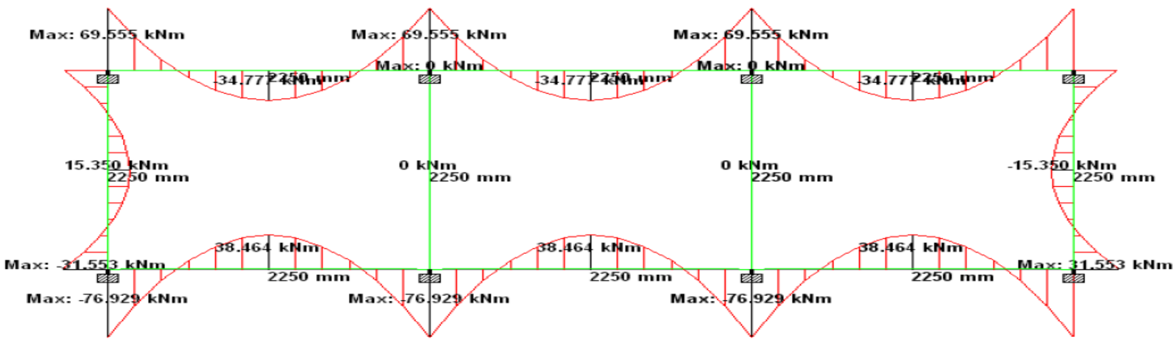


Fig 4: Bending moment diagram(staadpro)

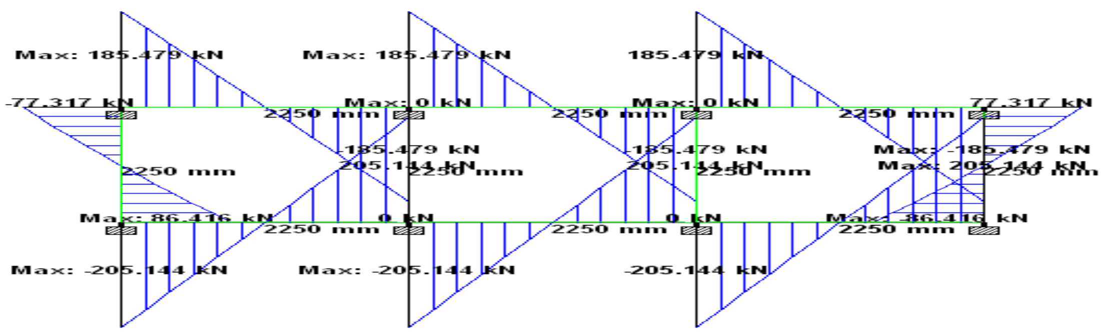


Fig 5: Shear force diagram (Staadpro)

Table 4: STRUCTURAL DESIGN OF REINFORCED CONCRETE TRIPLE BOX CULVERT

REFERENCES	SYMBOLS	CALCULATIONS	OUTPUT	REMARK
BS 8110-1,1997				
Design				
Wall	M	52.82	KNm	
Cover	c	40.00	mm	
Main bar diameter	Φ	16.00	mm	
Overall depth	h	250.00	mm	
Width	b	1000.00	mm	
Effective depth	d	202.00	mm	
Grade of high yield steel	fy	380.00	N/mm^2	
Grade of mild steel	fyv	250.00	N/mm^2	
Grade of concrete	fcu	25.00	N/mm^2	
Design coefficient	K	0.05		
Lever arm	Z	189.62	mm	
Area of steel required	Asreq	771.63	mm^2/m	

Area of steel provided	Asprov	893.00	mm^2/m	Y16-225 c/c(NF)
Top slab				
	M	126.99	KNm	
Cover	c	40.00	mm	
Main bar diameter	Φ	20.00	mm	
Overall depth	h	300.00	mm	
Width	b	1000.00	mm	
Effective depth	d	250.00	mm	
Grade of high yield steel	fy	380.00	N/mm^2	
Grade of mild steel	fyv	250.00	N/mm^2	
Grade of concrete	fcu	25.00	N/mm^2	
Design coefficient	K	0.08		
Lever arm	Z	224.90	mm	
Area of steel required	Asreq	1564.10	mm^2/m	
Area of steel provided	Asprov	1800.00	mm^2/m	Y20-175 c/c(B)
Bottom slab				
	M	141.35	KNm	
Cover	c	40.00	mm	
Main bar diameter	Φ	20.00	mm	
Overall depth	h	300.00	mm	
Width	b	1000.00	mm	
Effective depth	d	250.00	mm	
Grade of high yield steel	fy	380.00	N/mm^2	
Grade of mild steel	fyv	250.00	N/mm^2	
Grade of concrete	fcu	25.00	N/mm^2	
Design coefficient	K	0.09		
Lever arm	Z	221.66	mm	
Area of steel required	Asreq	1766.47	mm^2/m	
Area of steel provided	Asprov	2090.00	mm^2/m	Y20-150 c/c(B)
Support reinforcement for top slab				
	M	79.23	KNm	
Cover	c	40.00	mm	
Main bar diameter	Φ	20.00	mm	

Overall depth	h	300.00	mm	
Width	b	1000.00	mm	
Effective depth	d	250.00	mm	
Grade of high yield steel	fy	380.00	N/mm^2	
Grade of mild steel	fyv	250.00	N/mm^2	
Grade of concrete	fcu	25.00	N/mm^2	
Design coefficient	K	0.05		
Lever arm	Z	235.02	mm	
Area of steel required	Asreq	933.92	mm^2/m	
Area of steel provided	Asprov	1010.00	mm^2/m	Y16-200 c/c(T)
Bottom slab				
	M	88.32	KNm	
Cover	c	40.00	mm	
Main bar diameter	Φ	20.00	mm	
Overall depth	h	300.00	mm	
Width	b	1000.00	mm	
Effective depth	d	250.00	mm	
Grade of high yield steel	fy	380.00	N/mm^2	
Grade of mild steel	fyv	250.00	N/mm^2	
Grade of concrete	fcu	25.00	N/mm^2	
Design coefficient	K	0.06		
Lever arm	Z	233.16	mm	
Area of steel required	Asreq	1049.28	mm^2/m	
Area of steel provided	Asprov	1150.00	mm^2/m	Y16-150 c/c(T)
Deflection				
Service stress	fs	214.12	N/mm^2	
	M/bd^2	2.26	N/mm^2	
Modification factor	Mf	1.24		
support condition	Sc	26.00		
Required depth	dreq	69.63	mm	TRUE
Shear along bottom slab				
Maximum shear	V	229.39	KN	
shear stress	$\square$	0.92	N/mm^2	
	100Asp/bd	0.84		
	$\square_c$	0.67	N/mm^2	TRUE

Links spacing				
	Asv/Sv	1.68		R12-125 c/c

Design Formulae

Effective depth d = h-c –Φ/2

Design coefficient K = M/bd^2f_{cu}

Lever arm $Z = d\left[0.5 + \sqrt{0.25 - \frac{K}{0.9}}\right]$

$$AS_{req} = \frac{M}{0.95 f_y Z}$$

Modification Factor $M_F = 0.55 + \left[\frac{477 - f_s}{120\left(0.9 + \frac{M}{bd^2}\right)}\right]$, Where service $f_s = \frac{2}{3} f_y \frac{As_{req}}{As_{prov}}$

Table 5: End Moments (KNm)

MEMBER	SPREADSHEET	STAADPRO	Difference (%)
AB	-44.07	-69.56	-57.84
AH	44.07	76.93	-74.56
BA	39.13	69.56	-77.77
BC	-39.13	-69.56	-77.77
CB	79.06	69.56	12.02
CH	-9.12	0	100.00
CD	-76.93	-69.56	9.58
DC	73.18	69.56	4.95
DG	5.87	0	100.00
DE	-73.83	-69.56	5.78
ED	53.37	69.56	-30.34
EF	-53.37	-31.55	40.88
FE	40.95	31.55	22.95
FG	-40.95	-76.93	-87.86
GF	87.11	76.93	11.69
GD	-2.61	0	100.00
GH	-84.5	-76.93	8.96
HG	84.37	76.93	8.82
HC	0.95	0	100.00
HA	-85.32	-76.93	9.83

Table 6 : Span Moments (KNm)

MEMBER	SPREADSHEET	STAADPRO	Difference (%)
AB	43.25	15.35	64.51
BC	126.99	34.77	72.62
CD	107.96	34.77	67.79
DE	116.55	34.77	70.17
EF	52.82	15.35	70.94
FG	141.35	38.46	72.79
GH	116.55	38.46	67.00
HA	135.88	38.46	71.70
CH	0	0	0.00
DG	0	0	0.00

Table 7 :Property of material

Material	Concrete
Modulus of Elasticity (E)	$21.718KN/m^2$
(Poisson's ratio)	$170 \ X10^{-3}$
Density(ρ)	$2402.615Kg/m^3$

Discussion

End moments (Support moment) (from table 5)

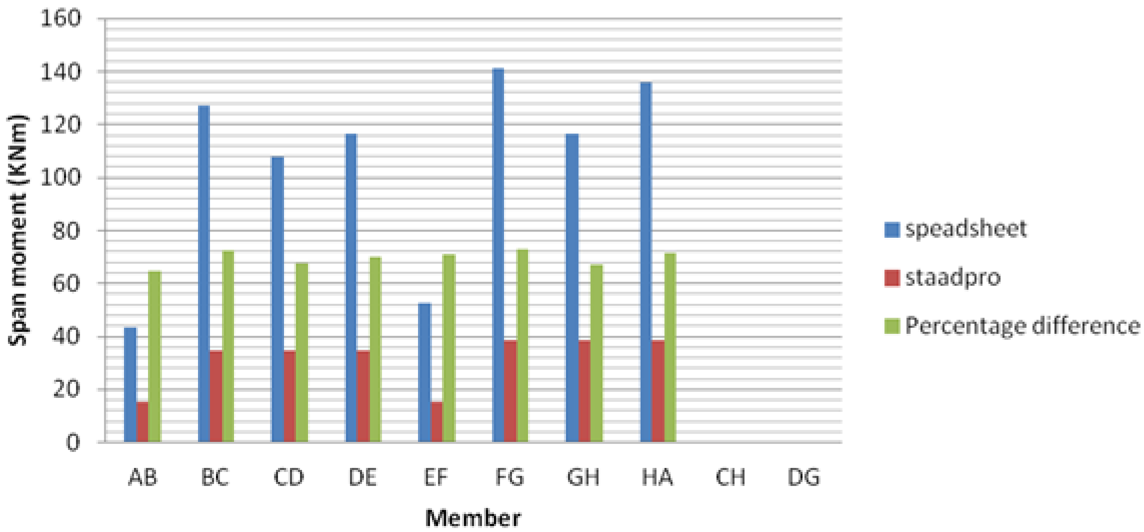
In computation of End moment (support moment) there was large variation using spreadsheet and staadpro as it has been observed that M^F_{AB} Spreadsheet = -44.07KNm while that of M^F_{AB} staadpro = -69.56KNm difference of -25.49KNm which is of 57.82% less than fixed end moment from staad and this will increase the area of reinforcement required and even lead to increase in section of concrete for the wall. For the bottom slab having maximum support moment (M^F_{GF}) of 87.11KNm from spreadsheet while that of 76.93KNm from Staadpro which has difference of 10.18KNm over staadpro and difference of 11.69% greater than staadpro output , similarly for top slab having maximum support moment(M^F_{CB}) of 79.06KNm spreadsheet and produced 69.56KNm from staadpro has a difference of 12.60KNm which has 12.02% more than staadpro output.

Span moments (from table 6)

It was observed that wall has maximum span moment M_{AB} = 52.82KNm from spreadsheet which percentage difference of 70.94% over M_{AB} = 15.35 KNm from staad.. The top slab has maximum Span moment M_{BC} = 126.99KNm from spreadsheet which is of 72.62% more than Fixed spam moment M_{BC} = 34.77KNm from staadpro. Bottom slab has maximum span M_{FG} = 141.35KNm from spreadsheet and that of staadpro produced 38.46KNm which has 72.79% difference more than M_{FG} = 38.46 KNm.

Shear force

The shear force is approximately the same for both (spreadsheet and staadpro)



Conclusion

It was observed that there was increase in end moments and span moments using spreadsheet because iteration number was distributing moments eight (8) times and from staadpro cannot been known due to assumption in which software had been written and developed and that of spreadsheet can be seen visually on excel sheet. The result produced by spreadsheet is realistic and dependable if compared to manual hand calculation.Young structural engineers must be able to write and develop program that will facilitate and make designs easy and in such a way it will be clearly understood on spreadsheet. The use of spreadsheet to write and develop program should be taken as crucial and integral part of curriculum in both universities and polytechnics especially in Engineering because the formulae are not hidden and well known to engineers.

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