A COMPTABILITY STUDY ON DESIGN AND ANALYSIS OF REINFORCED CONCRETE STRUCTURAL DESIGN USING SOFTWARE

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***Abstract*-It has been asserted in literature that the understanding of the software used today is the urgent necessity of the moment in order to match the pace of infrastructural development. This study is undertaken with the objective of checking the comptability of results obtained for the design of basic structural elements of Reinforced Cement Concrete (RCC) using popularly used software STAAD Pro, ETABS and SAP-2000.For this purpose the design results of most commonly used software are validated with manual design by Indian standards to gain the confidence of the users. The basic elements of structures such as beams, column and a simple frame have been discussed. The results for analysis of shear force and bending moment of beams and columns are comparable in all the cases except for the frame when STAAD Pro, ETABS and SAP-2000 are used. For all elements the results obtained from software differed significantly from the results obtained through manual calculations using Kani's method.**

Keywords- Computations, ETABS, SAP-2000, STAAD Pro, Shear force, bending moment

I. INTRODUCTION

The design of a simple building in the earlier times used to take at least a week. However, the design of complicated structures can now be done within a week's time and with more accuracy using a host of software available in the market. Subramanian N. [1] is of the opinion that these software should be regarded as mere tools in the hand of structural engineer. Designer should be aware of any assumptions used and limitations of the programs in the software. Subramanian N. [1] further put the example that some computer programs ignore compression steel when maximum allowable reinforcement in a concrete beam is determined resulting into a larger section. A hard fact which the society faces today is that many of the fresh graduates have not even approached to the design software used in market during their study. Therefore, these engineers have no other option but are bound to blindly accept the results given by the computers. Naghipour-et-al [2] used finite element program ETABS software to find the location of plastic hinge away from the joint location in eccentrically braced frame in 4, 7 and 10 story building. Sharma-et-al [3] studied a 3D framed RC using pushover analysis by increasing the load in small increment till failure with the help of software. They devised failure modes for the beam, column and joint. His study helped the engineers to focus on the weak points of structures to be taken care while designing a structure. Azam and Hosur [4] used ETABS software studied the provision of shear wall placed symmetrically in the building using elastic analysis for strength, stiffness and damping to make building safer.

Attempts have, however, started to verify and gain confidence for the validity of various software. Prashanth-et- al [5] compared these software and concluded that area of steel required by using ETABS was less. Hu-et-al [6] studied the response spectrum, time history and linking slab in plan using software SAP-2000, ETABS, MIDAS/GEN and SATWE software for a multistory. He concluded that ETABS is more suitable for regular buildings where as SAP-2000 is more suited to space structures, oblique column and gymnasiums. Al-Tamimi-et-al[7] compared the different construction material in three buildings using software ETABS, SAFE and ACI 365 to find the most reliable and beneficial material to be used for the structures. Kumar-et-al [8] studied the building on sloping ground using software ETABS and SAP-2000. They considered seismic forces as per I.S:1893-2002 and stressed the need for proper designing of structure on sloping ground.

Sabeer and Peera [9] compared the results obtained from STAAD Pro and ETABS for a RCC building subjected to lateral and vertical loads and concluded that both software provided different results whereas the difference had not been significant. Rana [10] compared the different aspects of a component design of a building using different software STAAD Pro, STRUDS and ETABS software. He concluded that the ETABS

gave more economical design than the STAAD Pro and STRUDS. Baral and Yajdani [11] studied five models one with shear wall and four without shear wall using software ETABS to verify how the bending moment, shear force in beam and axial force in the column change by changing the position of the shear walls in the building. Jennifer and Jegidha [12] reviewed the literature of various researchers on the different codes to find which code gives better performance during earthquake. They used software ETABS and SAP-2000 for analysis. He used various codes to find which code gave best results. Leonetti-et-al [13] proposed the efficient treatment of load combination to make the shakedown analysis more affordable tool for practical applications. They used the sap-2000 for analysis. Ramya and Saikumar [14] also compared these software and concluded that area of steel required by using ETABS was less.

Nguyen-et-al [15] studied the fifteen storied building for soil structure interaction on a shallow foundation using ABAQUS software and concluded that the size of the foundation influences the lateral deformation of midsized building which is important information to the design engineers. Ahmed Farghly [16] studied the location of shear wall in 12 storied building using SAP-2000 software which will help the design engineers for better building design. Massumi and Mohammadi [17] devised the evaluation criteria for a seismic behavior of a structure. Gorgun [18] investigated the column beam connection of skeletal structures for stability in semi-rigid frames using computer based method. He pointed out that economies can be achieved by second order (deflection induced) due to reduction in effective length of a column.

Purulekar-et-al [19] studied the seismic performance of a shear wall considering two parameters ultimate load and ultimate drift, verified it analytically and experimentally. They further highlighted the failure pattern, capacity and performance of a shear wall.

This study has been undertaken with the objective that the results obtained from the design software available in the market and generally used for analysis and design of structures by the engineers such as STAAD Pro, SAP-2000 and ETABS confirm theoretical background and various guidelines such as Indian Standards [20-22].

II. PROBLEM DEFINATION

In order to achieve above objective, basic elements of structures i.e. beams, column and simple frame were analyzed and designed. These elements were analyzed using all the three software and the results were compared with the manual calculations using Kani's method and IS-456 [20-22]. The details are as under:

A. Fixed Beam

The prismatic beam of sides 0.3mx0.3m and span 7m is loaded with uniformly distributed load under fixed end conditions using all the three software ETABS, SAP-2000 and STAAD Pro [23-25].

The results are compared with the manual calculations for the following data.

Size of beam=0.3mx0.3m

Span of beam=7m

Load = Dead load + 20kN/m

Grade of concrete: M-20 as per IS: 456-2000

Grade of Steel: Fe415 as per IS: 1786-2008

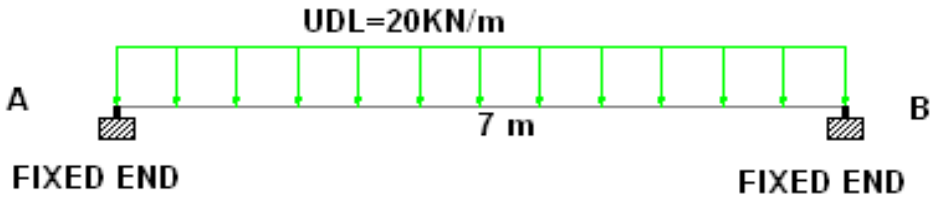

Fig.1 Fixed beam

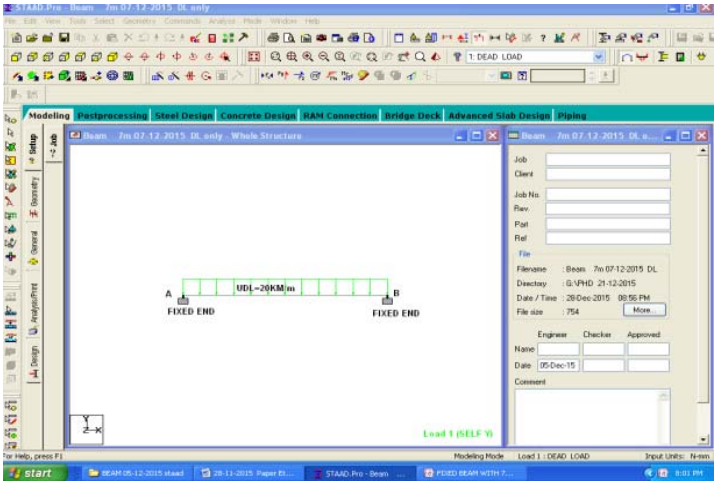

Fig.2 Beam analysis by software

B. Column with point load

The column of 0.3mx0.3m of length 3.5m is considered. The column is loaded with axial vertical load on top and fixed at the bottom end. The results are compared with the manual calculations for the following data.

Size of Column=0.3mx0.3m

Load=Dead load=500kN

Length of Column=3.5m

Grade of concrete: M-20 as per IS: 456-2000

Grade of Steel: Fe415 as per IS: 1786-2008

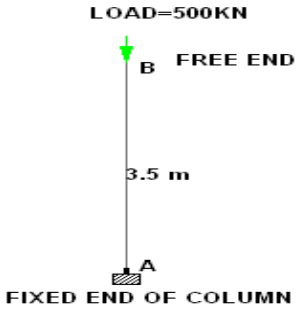

Fig.3 Column with one end fixed other free

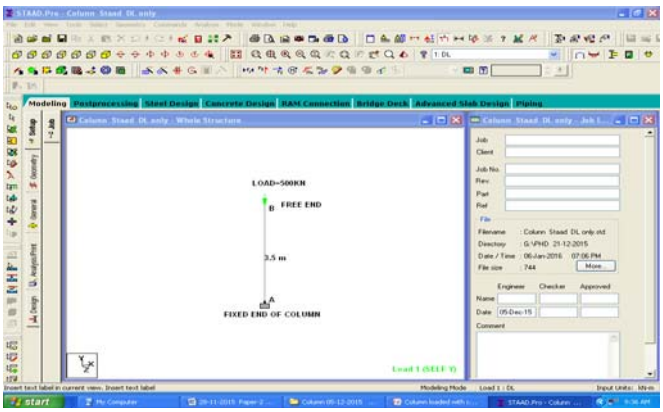

Fig.4 Column analysis by software

C. Cantilever beam

The prismatic cantilever beam of size 0.3mx0.3m with one end 'A' fixed and free end 'B' of span 7m is loaded with concentrated load at free end .The structure is analyzed using all the three software ETABS, SAP-2000 and STAAD Pro. [20-22] and results are compared with the manual calculations for the following data.

Size of cantilever beam=0.3mx0.3m

Length of cantilever beam=7m

Load = Dead Load+10kN at free end

Grade of concrete: M-20 as per IS: 456-2000

Grade of Steel: Fe415 as per IS: 1786-2008

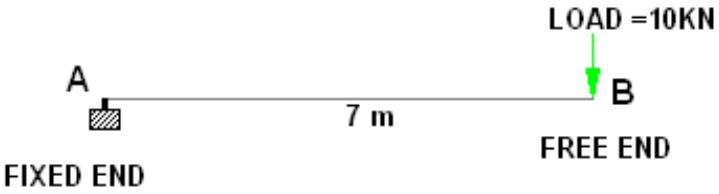

Fig.5 Cantilever Beam loaded at free end

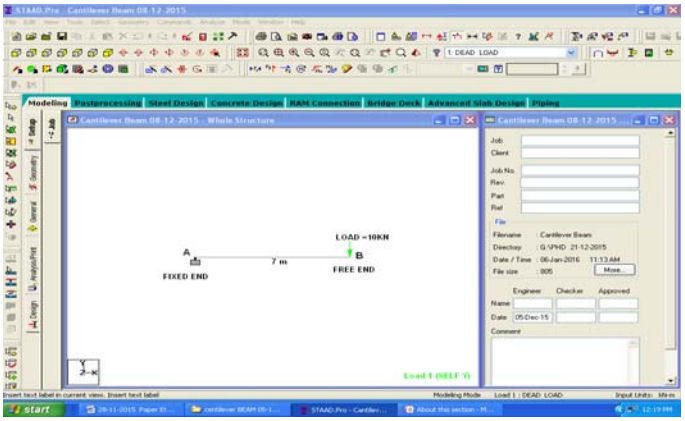

Fig. 6 Cantilever beam analysis by software

D. Portal frame

A portal frame with beam size 0.3m×0.3m and column size 0.3m×0.3m having concentrated load on one span and uniformly distributed load on the other span as shown in the Figure7 is considered. Modeling and analysis of the structure are done separately using software ETABS, SAP-2000 and STAAD Pro. [20-22].The results obtained are compared with manual calculations using Kani's method for the following data.

Length of Beam AD=2m

Length of Beam DB=4m

Height of Column=4m

Size of Beam AD=300mm x 300mm

Size of Beam DB=300mm x 300mm

Size of Column CD=300mm x 300mm

Grade of concrete: M-20 as per IS:456=2000

Grade of Steel: Fe415 as per IS: 1786=2008

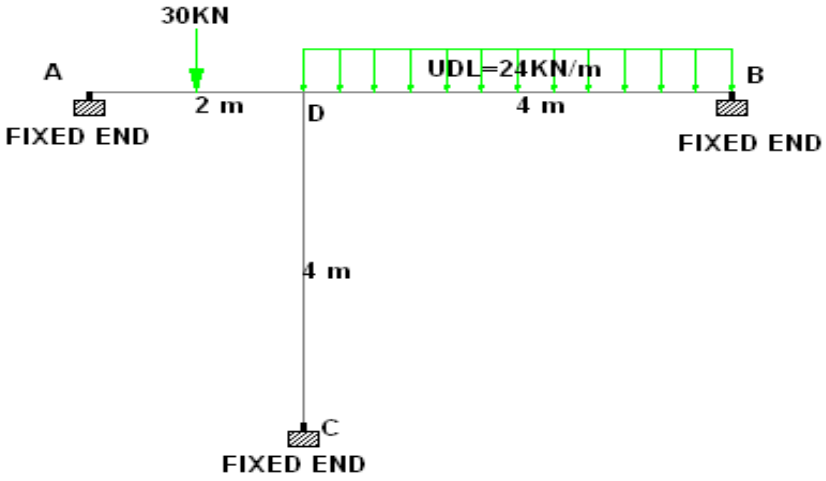

Fig.7 Portal frame

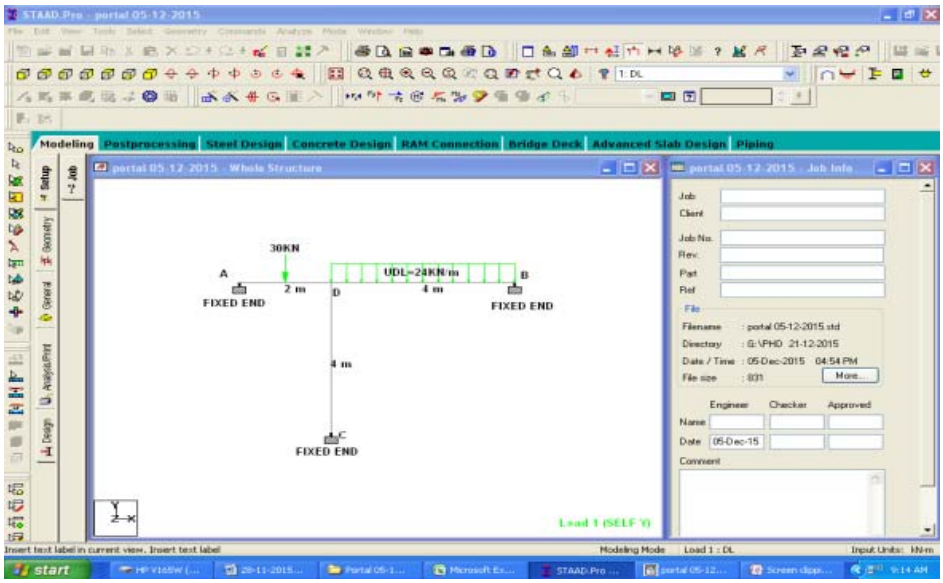

Fig.8 Portal frame analysis by software

III. RESULTS AND DISCUSSION

Results as obtained from ETABS, SAP-2000 and STAAD Pro [20-22] and from Kani's method are presented below and have been discussed further.

A. Fixed Beam Results

The results output of a sample beam for all the three software ETABS, SAP-2000 and STAAD Pro. Obtained have been tabulated. Table 1 is for the bending moment at five different locations i.e. at end A, 1/4L,1/2L,3/4L and end B.

Table-1 Comparison of Bending Moment results for fixed beam.

OUTPUT TYPE	LOCATION	STAAD Pro	ETABS	SAP-2000	THORETICAL VALUE (Manual Calculation)
Bending Moment (KN-m)	End 'A'	-135.489	-135.489	-136.278	-137.813
	¼ point	-16.937	-15.899	-15.992	-17.036
	½ point	-67.745	-67.704	-68.139	-68.907
	¾ point	-16.937	-15.899	-15.992	-17.036
	End 'B'	-135.489	-135.489	-136.278	-137.813

Table 2 shows the shear force at five different locations i.e. at end A, 1/4L, 1/2L, 3/4L and end B.

Table-2Comparison of Shear Force results for fixed beam.

OUTPUT TYPE	LOCATION	STAAD Pro	ETABS	SAP-2000	THEORETICAL VALUE (Manual Calculation)
Shear Force (KN)	End 'A'	-116.133	-116.130	-116.810	-118.125
	¼ point	-58.067	-58.065	-58.404	-58.407
	½ point	0	0	1.71E-13	0
	¾ point	-58.067	-58.065	-58.404	-58.407
	End 'B'	-116.133	-116.130	-116.810	-118.125

The tensile and compressive steel obtained are for the fixed beam for all the three software and with the theoretical value calculated with from SP-16 have been shown in Table 3.

Table-3 Comparison of tensile and compressive steel for fixed beam.

OUTPUT TYPE	STAAD Pro	ETABS	SAP-2000	THEORETICAL VALUE (Calculation by SP-16)
Factored B.M. (KN-m)	-135.489	-135.489	-136.278	-137.813
Tensile steel $A_{st}(mm^2)$	1073.54	825	851	885.225
Compressive Steel$A_{sc}(mm^2)$	1760.46	1598	1606	1630.150
Total Area of Steel(mm^2)	2833.54	2423	2457	2515.375

B. Column Results

The result obtained for the column for all the three software ETABS, SAP-2000 and STAAD Pro. [20-22] have been tabulated in Table 4.

Table-4 Comparison of results for Steel in Column

OUTPUT TYPE	STAAD Pro	ETABS	SAP-2000	THEORETICAL VALUE
Steel Quantity(mm^2)	682.63 (mm^2)	787(mm^2)	720(mm^2)	720(mm^2)

Table 5 shows the comparison of quantity of concrete given by all three software ETABS, SAP-2000 and STAAD Pro along with theoretical values

Table-5 Comparison of results for concrete quantity.

OUTPUT TYPE	STAAD Pro	ETABS	SAP-2000	THEORETICAL VALUE
Concrete Quantity (m^3)	0.32	0.315	0.315	0.315

C. Cantilever Beam Results

The results obtained for a simple cantilever beam for all the three software ETABS, SAP-2000 and STAAD Pro. [20-22]are tabulated. Table 6 shows the bending moment at five different locations i.e. at end A, 1/4L, 1/2L, 3/4L and end B.

Table-6 Comparison of results for cantilever beam for bending moment.

OUTPUT TYPE	LOCATION	STAAD Pro	ETABS	SAP-2000	THEORETICAL VALUE
Bending Moment (KN-m)	Fixed End 'A'	-182.93	-182.92	-187.66	-187.69
	¼ point	-122.586	-122.685	-125.353	-125.261
	½ point	-71.98	-71.98	-73.17	-73.17
	¾ point	-31.1205	-31.2195	-31.5225	-31.418
	Free End 'B'	0	0	7.41E-14	0

Table 7 shows the shear force of a cantilever beam at five different locations i.e. at end A, 1/4L, 1/2L, 3/4L and end B.

Table-7 Comparison of shear force results for cantilever beam.

OUTPUT TYPE	LOCATION	STAAD Pro	ETABS	SAP-2000	THEORETICAL VALUE
Shear Force (KN)	Fixed End 'A'	-37.266	-37.260	-38.618	-38.625
	¼ point	-31.699	-31.695	-32.713	-32.730
	½ point	-26.133	-26.130	-26.809	-26.730
	¾ point	-20.566	-20.565	-20.904	-20.905
	Free End 'B'	-15	-15	-15	-15

In Table 8 steel has been compared for the cantilever beam thorough all the three software ETABS, SAP-2000 and STAAD Pro. with the theoretical value calculated as per I.S. code-2000.

Table-8 Comparison of results for cantilever beam for steel.

OUTPUT TYPE	AREA OF STEEL	STAAD Pro	ETABS	SAP-2000	THEORETICAL VALUE
Steel By Software	Factored B.M. (kNm)	-182.930	-182.930	-187.664	-187.688
	$A_{st(}mm^2)$	2316.96	2123	3216(O/S)*	-
	$A_{sc(}mm^2)$	1636.36	1362	2477	-
	Total Area of Steel (mm^2)	3953.32	3485	5693	-

(O/S)*-Indicates that element is overstressed.

D. Portal Frame Results

The results obtained for a simple portal frame from ETABS, SAP-2000 and STAAD Pro. [20-22] are tabulated in Table 9.

Table-9 Comparison of bending moment results for portal frame.

OUTPUT TYPE	BEAM	LOCATION	STAAD Pro	ETABS	SAP-2000	THEORETICAL VALUE (Kani's Method)
Bending Moment M_z (KN-m)	AD	A	7.290	7.040	7.093	2.063
		D	28.808	28.799	28.934	29.625
	BD	B	59.007	59.006	59.302	9.188
		D	39.872	39.867	40.057	38.813
	CD	C	5.460	5.459	5.488	4.593
		D	11.064	**9.825**$	11.126	9.186

$-9.825 -Value taken at effective depth of beam face for column.

In Table 10 the steel has been compared for the simple portal frame for all the three software ETABS, SAP-2000 and STAAD Pro. with the theoretical value (IS-456:2000).

Table-10 Comparison of steel results of portal frame.

ELEMENT	AREA OF STEEL	STAAD Pro	ETABS	SAP-2000	THEORETICAL VALUE
AD (Beam)	Max. Factored B.M.(KN-m)	28.808	28.799	28.934	29.625
	$A_{st(}mm^2)$	165.29	233	233	420.79
	$A_{sc(}mm^2)$	359.42	251	317	Nil
	Total Area of Steel (mm^2)	524.71	484	550	420.79
BD (Beam)	Max. Factored B.M.(KN-m)	59.007	59.01	59.302	38.813
	$A_{st(}mm^2)$	331.50	365	468	715.37
	$A_{sc(}mm^2)$	781.24	731	736	Nil
	Total Area of Steel (mm^2)	1112.74	1096	1204	715.37
CD (Column)	Max. Factored B.M.(KN-m)	7.376	6.55	7.417	9.186
	$A_{C(mm}{}^2)$	452.93	720	720	720(min0.8%)

Table 11 compares the bending moment output of all the three software ETABS, SAP-2000 and STAAD Pro. with the theoretical value calculated by Kani's methods at the mid points of a portal frame.

Table-11 Comparison of results of bending moment for beams at mid span for portal frame.

OUTPUT TYPE	BEAM	LOCATION	STAAD PRO	ETABS	SAP-2000
Bending Moment Mz (KN-m)	AD	Mid Point	-6.177	-6.171	-6.174
	BD	Mid Point	-28.923	-28.328	-29.068
	CD	Mid Point	2.802	2.804	2.819

Table 12 compares the reaction of a simple portal frame given by three software ETABS, SAP-2000 and STAAD Pro. along three axis X, Y, Z .

Table-12 Comparison of reactions for portal frame at support.

LOCATION	DIRECTION	STAAD Pro	ETABS	SAP-2000	THEORETICAL VALUE
Reactions At Fixed Support 'A' (N)	x	-1836.021	-1836.46	-1845.91	1147.50
	y	9858.397	9867.39	9969.77	23550
	z	378.737	0	0	0
Reactions At Fixed Support 'B' (N)	x	918.011	918.23	922.95	1147.50
	y	55430.470	55430.48	55706.16	64605
	z	125.521	0	0	0
Reactions At Fixed Support 'C' (N)	x	2754.032	2754.70	2768.86	1147.50
	y	81916.558	81906.13	82817.42	79405.50
	z	504.258	0	0	0

IV. DISCUSSION

The results obtained after the analysis for the four different basic structural elements beam, column, cantilever beam and portal frame are discussed in sections 4.1, 4.2, 4.3 and 4.4 below.

A. Fixed Beam

The results obtained for design of fixed beam have been shown in **Table (1-3)**. It was observed that there was no significant difference in analysis for bending moment and shear force for all the cases. The value of steel required as obtained from ETAB, SAP-2000 and Kani's method hardly differ by 10%. However, the steel required as obtained by STAAD Pro differs significantly by more than 10% as compared to the steel requirement obtained by Kani's method. The amount of reinforcement as obtained by STAAD Pro is more than what is required by a balanced section. Hence, this violates the basic philosophy of limit state design [20] by producing an over reinforced section.

B. Column

The results obtained for design of the column have been shown in **Table (4-5).**The analysis shows that there is no significant difference in the quantity of steel and concrete for all the cases. The values of steel given by SAP-2000 are exactly same compared to theoretical methods and the results of ETABS are hardly different by 10%. The amount of reinforcement given by STAAD Pro is less than minimum required (0.8% of cross-section as per I.S. code). It is again violates the requirements of IS: 456 -2000[20].

C. Cantilever Beam

The results obtained for design of a cantilever beam for has been shown in **Tables (6-8).** It is clear from the table values that there is no significant difference in the analysis and variation is less than 10%. **Table 8** shows the values of steel for a cantilever beam with different software and theoretical value as per Indian Standard requirements. Steel area given by SAP-2000 is highest and the software shows that the beam is also over-stressed [23]. STAAD Pro shows 13.42% more steel as compared to ETABS although the moments given by

both the software is same. However the section of beam is over reinforced and cannot be designed as per IS-456:2000 Code [20]. Therefore, it is observed that the beam section designed using different software had been over-reinforced and therefore basic inherent advantage of limit state design is not met.

C. Portal Frame

The bending moment for the portal frame given in **Table 9** shows the variation at the fixed ends A and B as compared to the theoretical values of bending moment. The variation of bending moment at the fixed end A is 253.36%, 241.25%, 243.82%, respectively, for STAAD Pro, ETABS and SAP-2000 software compared to theoretical value. The variation of bending moment at the fixed end B is 542.21%, 542.21%, 545.43%, respectively, for STAAD Pro, ETABS and SAP-2000 software compared to theoretical value. This is due to change in the rigidity of the joint at the end of the beam making it unstable due to instability conditions at the ends providing degree of freedom in one or more direction (F_x, F_y, F_z and M_x) [23,25]. The values in ETABS show the variation on the account that these values are given at the effective depth from the face of the beam. **Table 10** shows steel provided in beam AD for all the three software STAAD Pro, ETABS and SAP-2000 which is 24.70%, 15.02%, 30.95% respectively, more than the theoretical results though the bending moment given by all the three software is almost same (**Table 11**). Also, in case of beam BD, the steel determined by STAAD Pro, ETABS and SAP-2000, respectively, are 55.55%, 53.21% and 68.30% more as compared to the theoretical value. The design results of column matches with the theoretical value for ETABS and SAP software but the value of steel given by STAAD Pro is less than the permissible limit (0.8%) (IS-456; 2000) [20] specified by the IS-456 Code .**Table 12** shows the values of reactions given by STAAD Pro, ETABS and SAP-2000 software. It is observed that there is insignificant variation along X-axis and Y-axis but there is a significant variation of force along Z-axis because of more degree of freedom provided by instability condition [23, 25]. There is no significant variation in the values of ETABS and SAP-2000 but the variation is significant along 'Z' direction for STAAD Pro at the joint 'A', joint 'B' and joint 'C'.

V. CONCLUSIONS

- The comparison of analysis of force for the fixed and cantilever beams is closer to the theoretical value in case of SAP-2000. Moment in STAAD Pro and ETABS is on the lower side.
- The quantity of concrete provided for a fixed beam given by all the three software is same as that of theoretical value.
- The software provided required amount of steel in reinforced cantilever beam although the cantilever beam cannot be designed theoretically as under reinforced section using Indian Standards.
- There is no significant variation of shear force given by STAAD Pro, ETABS and SAP-2000 compared to theoretical value for the cantilever beam
- The fixed end moment in case of a portal frame showed significant variation at the fixed ends of a frame but the variation at continuous supports are within 5% compared to theoretical value.
- The area of steel results for ETABS and SAP-2000 exactly matches the theoretical value of steel in case of portal frame but the steel results given by STAAD Pro are less than minimum recommended by I.S. code.
- The results reactions at the supports for STAAD Pro, ETABS and SAP-2000 are almost same along X-direction and Y-direction but there is a huge variation along Z-axis on the account of instability condition in the joint.

All the three software STAAD Pro, ETABS and SAP-2000 give good approximation of the results for bending moments, shear forces, axial forces with the independent results designed manually for the same problem [20-25]. The area of steel shows a large variation of order of more than 5% even for the same moments. It is therefore concluded that more expertise is required to a Civil Engineer when more complicated structures are designed.

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