ANALYSIS OF LATERAL FORCES ON A MULTI-STORIED FRAME STRUCTURE USING D-VALUE METHOD AND ITS COMPARISON WITH FINITE ELEMENT METHOD

U. Waseem[*] and N. Aadil[**]

[*]Department of Civil Engineering University of Lahore, Lahore
[**]Department of Geological Engineering, UET, Lahore
[**]Corresponding Address: naadil@yahoo.com.au

ABSTRACT: Multi-storied frame structures have always been in the lime-light as far as research and theoretical development is concerned. The behavior of lateral forces on the structures is a specific area on which considerable research has been done over the last few decades. Several experiences of the last century have brought the attention of the engineers to such forces which, at times, were significant enough to change the design criteria. In Pakistan, considerations for such lateral forces had been made compulsory by the building control authorities across the country, and the same were welcomed, after the catastrophic disaster of October 2005. However, the developmental research in the field is still underway like in rest of the world. Most of the structural designers in Pakistan depend on Computer Aided Design software for analysis of lateral forces; however, significance of classical methods cannot be over-ruled. In this study, an attempt was made by studying the comparison between the design results of a multi-storied moment resisting frame structure in Karachi using the D-value method and ETABS software. There are several parameters on which the comparison could be based, but as the designers are mostly concerned about the design moments, the comparison is based upon the difference between the moments caused on respective joints by the lateral forces only. D-value method is not only a straightforward method but also may be considered to be the nearest compatible method to the finite element method (ETABS), for the analysis of lateral forces on super-structures, as its results showed a variation of only 20% with that of the results from ETABS. It is recommended for preferable use D-value method upon other methods of analysis when it comes to the scrutiny or verification of moments from the CAD software however, the difference between the comparative results may vary for type of structures other than the moment resisting frame structures.

Key words: Frame Structures, Lateral Forces, D-value Method, ETABS, CAD Software

INTRODUCTION

Multi-storied frame structures have always been in the lime-light as far as research and theoretical development is concerned which is why the maturity achieved in the field so far is quiet welcomed. It is indeed a very significant subject of structural engineering which has focused by the professionals to produce latest building techniques as to satisfy the modern challenges (Elliot and Colin, 2013; Ghosh et al., 2006; Horne, 1975; Wood, 1974). However, every step forward opens new horizons multiplying the areas of interests of the field. Moreover, the behavior of lateral forces on the structures is a specific area on which considerable research has been done over the last few decades. Several experiences of the last century have brought the attention of the engineers to such forces which, at times, are significant enough to change the design criteria (Chok, 2003; Johnson, 1994; Carter and Kulhawy, 1992). In Pakistan, considerations for such lateral forces had been made compulsory by the building control authorities across the country, and the same were welcomed, after the catastrophic disaster of October 2005. However, the developmental research in the field is still underway like in rest of the world.

Most of the structural designers in Pakistan depend on Computer Aided Designs software for analysis of lateral forces; however, significance of classical methods cannot be over-ruled (Astley, 1992). A designer often wants to compare the CAD results with that of the classical methods in order to verify that the software has analyzed the same case as desired. In compliance, the designer has to choose a method which is best compatible with the method followed by the software so as to get reliable comparison results. Today, several methods have been developed for the analysis of lateral forces among which the following are the most reliable;

1. Stiffness method,
2. Factor method,
3. Portal method,
4. D-value method

The above-mentioned methods are extensively used in design offices but every method has some advantage over other in particular case. It has been proved by previous researches that the D-value method shows the least difference between the results of finite element method which is used by most of the software as an analysis method (Muto, 1933). Also, it can analyze a single storey of interest rather than solving complicated and cumbersome calculations for the whole structure as in the case of other methods which favors its use, especially for the purpose of comparison where a designer may compare the results of a single storey of interest.

In order to compare and verify the two results, a designer must have a firm knowledge about the conventional difference between the two methods. This conventional difference may be worked out by conducting several case-studies and then analyzing the average differences of each case study so as to set a standard employing which one can predict the average difference in his case. There have been a couple of researches on such subject through which the average difference between the finite element method and D-value method was claimed to be around 35% (Hassoun and Manaseer, 2012). As these researches have been done mainly on built-up cases rather than on a real life structures, the claim needs to be supported by comparisons done on successful designs of existing structures. One such attempt is made here by studying the comparison between the design results of a multi-storied moment resisting frame structure in Karachi using the D-value method and ETABS software. There are several parameters on which the comparison could be based, but as the designers are mostly concerned with the design moments, the comparison is based upon the difference between the moments caused on respective joints by the lateral forces only.

MATERIALS AND METHODS

Etabs And D-Value Method: Most of the computer aided design software use finite element method for the analysis of structures. This method distributes the cross-sections of elements of the structure into several finite parts and analyzes them individually on work-energy principle. This makes the finite element method a powerful tool but requires cumbersome calculations, and is, therefore, only suitable for the software design (Astley, 1992). ETABS is a software which uses finite element method for the analysis of buildings and is believed to produce the most accurate results provided that analysis has been done considering the desired cases. Therefore, such results need to be verified by some manual method so as to confirm that the analysis has been done in the desired manner.

D-value method is one of the methods used for the analysis of lateral forces in most of the design offices. D-value method, being the most recent, is considered to be the most straightforward, uncomplicated and precise among the classical manual methods to analyze lateral forces (Muto, 1933). The D-value method solves the distribution of lateral forces to the beams and columns storey-wise depending upon the relative stiffness of the members. Hence, the D-value method considers a single storey at a time and distributes the storey shear within that storey rather than considering the whole frame, as done in most other methods.

Pre-defined parameters: The proposed plan is of a real life structure, a multi-storied building (G+13) located in north of Karachi. The structure is an ordinary moment resisting frame structure intended for residential use. Some changes have been made in the proposed plan, for example, shear wall has been excluded from the design to ease the calculations for the D-value method at this level. In addition, a stair tower has also been excluded from the plan as it proves to be a non-structural member which does not contribute in resisting lateral forces. However, these changes do not affect the behavior of the structure.

International code: The codes used for the design of the structure are:

ACI – 318 – 2002	(ACI-American Concrete Institute) for general design specifications
UBC – 97	(UBC-Uniform Building Code) for lateral forces

ACI – 318 – 2002 has been used for the design of all the structural members and all the load conditions and combinations used satisfy the code. UBC – 97 has also been used for the analysis of lateral forces including wind and seismic forces. The location of the structure suggests it to be considered in seismic zone 2B. The surrounding of the structure is such that the seismic forces govern over wind forces; however, it has also been verified theoretically.

RESULTS & DISCUSSION

To begin with, slabs were designed to get the appropriate load on the beam. One-way slabs, two-way slabs, cantilever slabs and sunk slabs are encountered which have been designed according to the specifications of the code. Live load of 40 psf for rooms, 60 psf for corridors and 100 psf for staircases were taken during the design calculations.

Tributary/catchment area was used for the approximation of load and excel based spreadsheet (Table 1) has been developed exclusively for the purpose so as to avoid any mistake calculations. The spreadsheet primarily calculates the axial force applied on the column storey-wise and also suggested its cross-section assuming the area of reinforcement as 1% of the suggested cross-section. This spreadsheet has also been used to calculate the total dead-weight of the structure which is required for the calculation of base shear and storey shear to perform seismic analysis.

Table 1: Tributary method calculation for approximation of load

CATCHMENT AREA FOR COLUMNS

SLAB THICKNESS =	5	INCHES
LIVE LOAD =	0.04	KSF
FINISHES =	0.036	KSF
WIDTH OF BEAM =	8	INCHES
DEPTH OF BEAM =	36	INCHES
WIDTH OF WALL =	6	INCHES
HIEGHT OF WALL =	7	FT
RENGTH OF CONCRETI	4	KSI
STOREY HIEGHT =	10	FT
RAPET WALL HIEGHT	4	FT

STOREY #	COLUMN	BEAM LENGTH (FT)	WALL LENGTH (FT)	SLAB AREA (FT^2)	SELF WT. OF COLUMN (KIPS)	TOTAL (KIPS)				MISCELLINEOUS (KIPS)	P_U (KIPS)	A_s ($INCH^2$)
						SERVICE LOAD		ULTIMATE LOAD				
						LIVE LOAD	DEAD LOAD	LIVE LOAD	DEAD LOAD			
PARAPET WALL	C/16	0.00	10.00	0.00	0.00	0.00	2.88	0.00	3.46		3.46	1.82
ROOF	C/16	0.00	0.00	0.00	1.01	0.00	3.89	0.00	4.67	181.00	185.67	97.51
12	C/16	33.00	27.50	180.00	1.54	7.20	226.91	11.52	272.30		283.82	149.06
11	C/16	33.00	27.50	180.00	1.88	14.40	268.74	23.04	322.49		345.53	181.47
10	C/16	33.00	27.50	180.00	2.21	21.60	310.56	34.56	372.68		407.24	213.88
9	C/16	33.00	27.50	180.00	2.55	28.80	352.39	46.08	422.87		468.95	246.30
8	C/16	33.00	27.50	180.00	2.88	36.00	394.21	57.60	473.06		530.66	278.71
7	C/16	33.00	27.50	180.00	3.22	43.20	436.04	69.12	523.25		592.37	311.12
6	C/16	33.00	27.50	180.00	3.56	50.40	477.87	80.64	573.44		654.08	343.53
5	C/16	33.00	27.50	180.00	3.89	57.60	519.69	92.16	623.63		715.79	375.94
4	C/16	33.00	27.50	180.00	4.23	64.80	561.52	103.68	673.82		777.50	408.35
3	C/16	33.00	27.50	180.00	4.56	72.00	603.34	115.20	724.01		839.21	440.76
2	C/16	33.00	27.50	180.00	4.90	79.20	645.17	126.72	774.20		900.92	473.17
1	C/16	33.00	27.50	180.00	5.23	86.40	686.99	138.24	824.39		962.63	505.58
0	C/16	33.00	27.50	180.00	5.57	93.60	728.82	149.76	874.58		1024.34	537.99
-1	C/16	0.00	0.00	0.00	5.57	93.60	728.82	149.76	874.58		1024.34	537.99

DEAD WIEGHT THROUGH THE COLUMN = 728.82 KIPS

The D-value method has been used for the analysis of seismic forces. The method distributes the storey shear to the exterior and interior beams and columns in a way that the extent of storey shear force distributed to each column is directly proportional to the stiffness of the column relative to the beams attaching to it. In this way, all the storeys have been analyzed in both the directions i.e. Alphabetical axis and Numerical axis, keeping one direction locked while working on the other at a time. The columns parallel to the considered direction, mentioned as "major columns" having greater stiffness, bear larger moments than that of the "minor columns" i.e. perpendicular to the considered direction. However, it is to be noted that the column which is considered as "major column" in one direction is a "minor column" when analyzing from the other direction. Similarly, the columns to which two beams are attached bear larger moments than those attaching with a single beam. The analysis produced two values of moments on each column(i.e. top moment of lower and bottom moment of upper storey), the sum of which was distributed to the beams in respective direction according to their relative stiffness. The working was done using excel based spreadsheets, one of which is shown as Table 2.

The modeling of the structure on ETABS has been done in accordance with that designed previously for D-value method. All the material properties of concrete and steel have also been defined as used previously. The slabs and the walls were assigned as area objects and the beams were assigned as line objects. Similar load combinations and design codes were used as in the manual design. The analysis was then run on static load cases including seismic effects which gave detailed results of the analysis.

The moments calculated from the manual design were then compared with that from ETABS at similar joints and the difference was worked out. The differences between the two results of other joints were then averaged and standard deviation of all the differences was then calculated.

SEISMIC ANALYSIS

UPPER 2ND TO 3RD **FLOOR** **Q =** 3205 **HEIGHT OF FLOOR =** 10 **ft**

SUM D = 10010

ALPHABETICAL DIRECTION

COLUMN	NO. OF COLUMNS	BEAM STIFFNESS												COLUMN STIFFNESS		K_C	K	a	D	Q_X	y	COL MOM	
		BOTTOM						TOP														TOP	BOTT
		B1	D1	K1	B2	D2	K2	B3	D3	K3	B4	D4	K4	BC	DC							KIP FT.	
C1MJ1	14	8	36	259.2	0	0	0	0	0	0	8	36	259.2	18	36	583.2	0.4	0.2	1484.5	475.3	0.5	169.8	169.8
C1MJ2	10	8	36	259.2	8	36	259.2	8	36	259.2	8	36	259.2	18	36	583.2	0.9	0.3	1794.5	574.6	0.5	287.3	287.3
C1MN1	16	8	36	259.2	0	0	0	0	0	0	8	36	259.2	36	18	145.8	1.8	0.5	1097.8	351.5	0.5	109.8	109.8
C1MN2	32	8	36	259.2	8	36	259.2	8	36	259.2	8	36	259.2	36	18	145.8	3.6	0.6	2986.0	956.1	0.5	149.4	149.4
C2MJ1	4	8	36	259.2	0	0	0	0	0	0	8	36	259.2	15	30	281.3	0.9	0.3	354.9	113.6	0.5	142.0	142.0
C2MN1	2	8	36	259.2	0	0	0	0	0	0	8	36	259.2	30	15	70.3	3.7	0.6	91.2	29.2	0.5	73.0	73.0
C2MN2	6	8	36	259.2	8	36	259.2	8	36	259.2	8	36	259.2	30	15	70.3	7.4	0.8	331.9	106.3	0.5	88.5	88.5
C3MJ1	4	8	36	259.2	0	0	0	0	0	0	8	36	259.2	18	30	337.5	0.8	0.3	374.6	119.9	0.5	149.9	149.9
C3MN1	8	8	36	259.2	0	0	0	0	0	0	8	36	259.2	30	18	121.5	2.1	0.5	501.7	160.6	0.5	100.4	100.4
C3MN2	12	8	36	259.2	8	36	259.2	8	36	259.2	8	36	259.2	30	18	121.5	4.3	0.7	992.7	317.9	0.5	132.4	132.4
∑	108																		10010	3205			

As ETABS is believed to produce the most accurate results when compared with other methods including D-value method, it has been used as a benchmark for working out the comparison (Geert, 2000). In compliance, the moments on similar joints were compared according to the respective axis considering each condition individually. For instance, the results achieved from ETABS considering the X-axis to be the major axis i.e. lateral force is considered to be applied parallel to X-axis were compared with the results obtained in alphabetical direction from the D-value method. Similarly, Numerical direction was compared with the results of Y-axis being the major axis. Keeping in view the criteria, top and bottom moments of all the columns of 1st, 4th and 8th storey of the structure was compared which gave the following results,

- The overall average difference between the moments obtained from ETABS and from D-value method was 20% which was in comparison with the results of Hassoun and Manaseer (2012).
- The percentage difference between the moments obtained from ETABS and from D-value method on the 1st storey was 17%. Further, moving upwards close to the middle of the building, the difference increased up to 24% on 4th storey. However, getting ahead of the mid-height of the structure, the percentage difference started to decrease again and was found to be 23% on 8th storey.

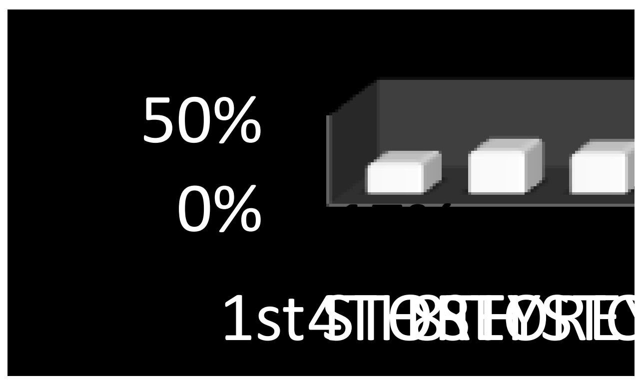

Figure 1: Percentage differences for different storey

- The difference was mainly governed by the directional cases, orientation and position of the columns as indicated by Muto, 1933.
- Interior columns have greater difference as compared to the exterior columns
- D-value produced greater value of moments when compared with ETABS in case of the columns which were parallel to the major axis,
- ETABS produced greater value of moments when compared with D-value method in case of the columns which were perpendicular to the major axis

Actions and stresses in a building must be calculated before seismic forces can be utilized in design. A series of rectangular frames under horizontal forces were analyzed to study the lateral stiffness of columns and the height of inflection points, and Muto (1933) he proposed lateral force distribution ratios (D-value) for interior (1.0) and exterior (0.5) columns, and for flexible frames (1.0) and shear walls (8 to 20). Lateral stiffness of columns was theoretically evaluated taking into account (a) flexural stiffness of the column, (b) stiffness of adjacent girders immediately above and below the column, and (c) support conditions at the column base. Story shear was distributed to columns in the story proportional to their lateral stiffness. The moment distribution of the column was determined by the column shear and the height of inflection point, which was evaluated taking into account (a) the relative location of story, (b) the stiffness of adjacent girders immediately above and below the column, (c) changes in the stiffness of the adjacent girders, and (d) the difference in inter-story height immediately above and below the column. The sum of column end moments at a joint was distributed to girder ends in proportion to the girder stiffness (Muto, 1933),

Conclusions

- In view of the results obtained from the practice, following conclusions were drawn;
- D-value method may be considered to be the nearest compatible method to the finite element method (ETABS), for the analysis of lateral forces on super-structures, as its result showed a variation of only 20% with that of the results from ETABS. Also, D-value method was the easiest and straightforward method among the others which did not require cumbersome calculations like others. Further, only a single storey of interest may be analyzed and verified with the help of D-value method avoiding the analysis of the whole structure. For such reasons, D-value method should be preferred upon other method of analysis when it comes to the scrutiny or verification of moments from the CAD software.
- The varying trends in the percentage difference of moments of different storey showed that the difference is minimum at the 1st and the last storey and were maximum at the mid-height of the structure.
- It should be noted that the interior columns showed greater percentage difference than that of the exterior columns. This was due to the fact that the D-value method did not consider the position of the columns with the same conditions and distributes the same moments even if it is an exterior or interior column, whereas, ETABS considered the difference between an exterior and interior column even in the same condition. This may be verified by referring to the work/volume diagram in ETABS that the exterior columns have greater energy and therefore take greater moments than that of the interior columns with the same conditions.
- However, the difference between the comparative results may vary for type of structures other than the moment resisting frame structures.

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