Use of Signed response quantities in Response Spectrum Analysis – A Case Study

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Abstract

In the static method of seismic analysis, it is assumed that the fundamental mode of vibration dominates the response and mass and stiffness of the structure are evenly distributed thus giving a regular mode shape. In tall and/or irregular buildings, these assumptions are invalid and a dynamic analysis needs to be performed. Dynamic analysis using Response Spectrum method is preferred as it is easy to use. Modal analysis is performed to compute modal responses and they are combined using modal combination methods (SRSS, CQC etc.) to get the maximum responses. Modal combination of the responses leads to absolute unsigned quantities. A structural element is designed on the basis of the worst algebraic load combination that leads to maximum stress resultants. Since member forces are expressed in local axes, unsigned member forces at the both ends of the members do not satisfy static equilibrium for the Response Spectrum load cases. Hence load combinations with these unsigned response quantities may lead to untenable and unrealistic member forces at the start and end of the member. This becomes more relevant for corner columns which may exhibit high axial tension/ uplift while considering unsigned Response Spectrum results. This problem can be easily eliminated if the sign of the responses of the dominant mode of vibration is considered. This has been clearly demonstrated in the present case study of twelve-story RCC hospital building situated in seismic zone four in West Bengal where unsigned response quantities resulted in a huge uplift force on a column which had to be designed for high tensile force. Considering the sign of the dominant mode, it was observed that the column was actually not experiencing huge tension. It can be inferred from the present case study that the responses obtained from modal combinations should be used for load combinations only with proper sign which is often not considered by designers.

Key Words: Fundamental mode; Response Spectrum Analysis; Modal Combination; Dominant Mode

1. Introduction

Response Spectrum Analysis is a probabilistic dynamic analysis performed when mass and stiffness of the structure are not evenly distributed (**Sen,** 2009). Response spectrum analysis is a technique for performing an equivalent static lateral load analysis of structures for earthquake forces (**HOUSNER** and **JENNINGS,** 1982). It is useful in the approximate evaluation of the reliability and safety of structures under earthquake forces. The major problem lies in the fact that the results of Response Spectrum analysis are absolute quantities as they are computed using modal combination methods like SRSS, CQC etc. (**Wilson,** 2002). The nature of the member forces cannot be determined. The member forces derived from a load combination involving a Response Spectrum load case may provide un-realistic results. If they are used in design of structural elements specifically columns, the design results will be erroneous. Some special consideration is required in the Response Spectrum analysis by which the nature of the member forces can be determined. The methodology that can be adopted to overcome the problem has been discussed in the present case study.

2. Objective of the present Research Work

The objective of the present research work may be outlined as follows-

- To report in brief the analysis and design considerations adopted for the present case study.
- To highlight how the unsigned response quantities in the in the response spectrum load cases may lead to unrealistic member forces
- To discuss explain how the column end forces are derived.

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- To discuss the methodology of using the signs of the dominant mode in the response quantities.
- To report the effect of signed Response Spectrum results in design.
- To provide guidance on the usage of signed Response Spectrum results for structural element design.

3. Brief Introduction to the Case Study

The case study reported in this paper consists of an administrative building constructed at Jalpaiguri district of West Bengal, India. The typical administrative building plan is shown in Fig-1.

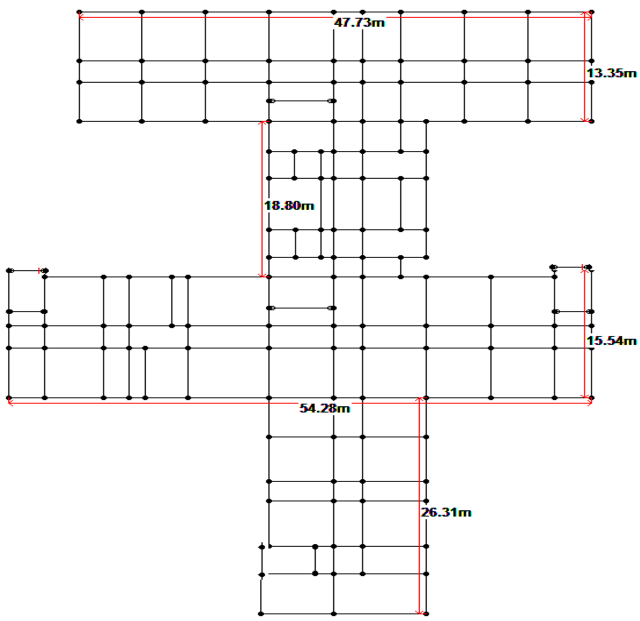

Fig-1.Typical Floor Plan

This is an eleven storied unsymmetrical building with more than 4,500 numbers of beams and columns. The typical column dimension was 900 mm x 900 mm and typical beam dimension was 350 mm x 500 mm. The building is in seismic zone IV and a dynamic analysis was proposed to capture dynamic responses of the building. The building was modelled, analysed and designed in STAAD.Pro V8i software. Fig-2 shows the 3D model prepared in the software.

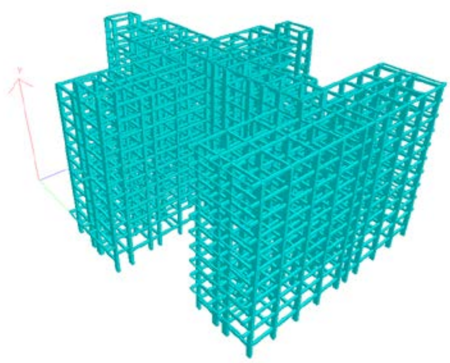

Fig.2- 3D model of the building

The model was analysed for Dead load, Live Load and Seismic forces. Response Spectrum analysis was performed. The structural elements designed with the forces envelop created with load combination as per the relevant Indian standards.

4. Statement of the actual Problem

While designing the structural elements with the so created force envelop, it was observed that the design output of some corner columns were unrealistic. A particular column bearing no. 2736 as demarcated in the software was designed as a column subjected to tension with bi-axial bending. It was a challenge for the designer to figure out root cause and find a resolution to the problem. Fig.3 shows the design output for the column.

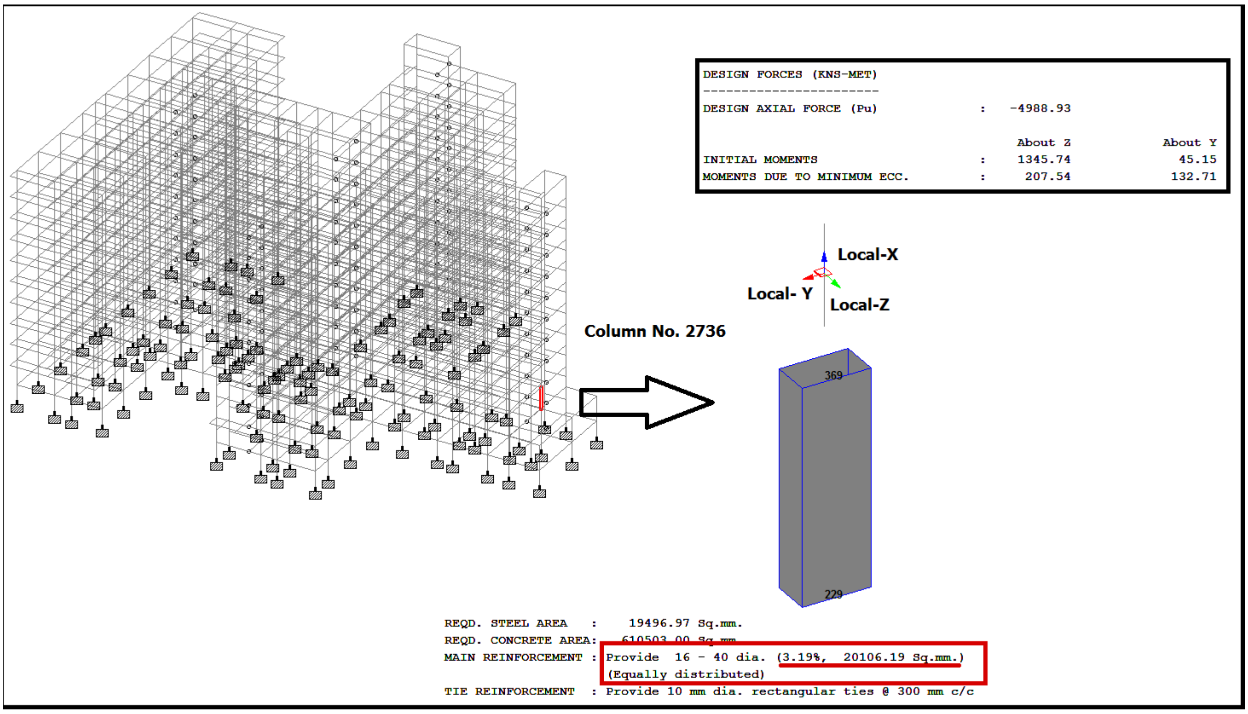

Fig.3- Column design output

5. Modifications needed in the Analysis & Design

It was observed that column considered in the case study has been designed as tension column. Column no. 2736 was experiencing huge tensile force under load combination 210. [0.9 times (Dead load +brick wall load) +1.5 Response spectrum load case in X direction]. Fig.4 shows member forces for the column for the critical load combination for which the column was designed

MEMBER END FORCES STRUCTURE TYPE = SPACE

ALL UNITS ARE -- KN METE (LOCAL)

MEMBER	LOAD	JT	AXIAL	SHEAR-Y	SHEAR-Z	TORSION	MOM-Y	MOM-Z
2736	210	229	4988.93	745.17	25.74	61.17	45.15	1345.74
		369	371.86	653.90	16.02	59.79	8.59	1119.75

Fig.4- Member forces details

The axial force at the start node and end node are both + ve violating the equilibrium condition of column. The nature of the axial force of the column cannot be determined. The worst effect will occur if the column is designed as a Tension column. The program is doing the same and the column is designed as a Tension column. The member forces results for the individual load cases can be seen from Fig-5.

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MEMBER	LOAD	JT	AXIAL	SHEAR-Y	SHEAR-Z	TORSION	MOM-Y	MOM-Z
2736	1	229	1829.40	36.78	-0.02	0.80	12.92	71.71
		369	-1778.43	-36.78	0.02	-0.80	-12.86	49.67
	3	229	761.12	13.93	5.42	-0.03	-9.48	22.89
		369	-761.12	-13.93	-5.42	0.03	-8.42	23.08
	4	229	1771.64	466.36	13.92	40.32	28.03	840.40
		369	1771.64	466.36	13.92	40.32	18.49	702.85
	210	229	4988.93	745.17	25.74	61.17	45.15	1345.74
		369	371.86	653.90	16.02	59.79	8.59	1119.75

Fig.5- Member forces details for all the load cases

It can be seen that axial force in the column is critical at the start node- node number 229. At this node, the axial force for load case 1, 3, 4 are 1829.4, 761.12 and 1771.64 KN respectively. The axial force at the same node for the load combination can be computed as (0.9 x 1829.40 + 0.9 x 761.12 + 1.5 x 1771.64) = 4988.928 KN. It can be inferred that the Response spectrum load case being unsigned quantity when added with other gravity load cases yields huge unsigned axial forces which is treated as tensile force in the design. This situation can be avoided by using signed Response Spectrum results. The mode having maximum mass participation is considered as dominant mode and all the response quantities are assigned the sign of dominant mode. On using the sign of the dominant mode, the members forces gets modified which is quite acceptable and can be used in design. Fig-6 shows the members forces on the column after using the sign of dominant mode.

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	4	229	-1771.64	466.36	-13.92	40.32	28.03	840.40
		369	1771.64	-466.36	13.92	-40.32	18.49	702.85
	210	229	-325.99	745.17	-16.02	61.17	45.15	1345.74
		369	371.86	-745.17	16.02	-61.17	8.59	1119.75

Fig.6- Members forces on the column after using the sign of dominant mode

It can be seen that the axial force of the governing load case has come down to a lower tension force which is apt for the design. Fig. 7 shows the design output for the same column.

The design axial for the critical load combination 210 is found to be 325.99 KN (tension). The percentage of reinforcement required is found to be 1.40.

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        C O L U M N   N O.   2736  D E S I G N   R E S U L T S

      M30                         Fe500 (Main)                  Fe415 (Sec.)

LENGTH:  3300.0 mm   CROSS SECTION:  600.0 mm X 1050.0 mm  COVER: 40.0 mm

** GUIDING LOAD CASE:  210 END JOINT:   229  TENSION COLUMN


DESIGN FORCES (KNS-MET)
-----------------------
DESIGN AXIAL FORCE (Pu)                 :    -325.99

                                             About Z              About Y
INITIAL MOMENTS                         :    1345.74               45.15
MOMENTS DUE TO MINIMUM ECC.             :      13.56                8.67

SLENDERNESS RATIOS                      :      -                  -
MOMENTS DUE TO SLENDERNESS EFFECT       :      -                  -
MOMENT REDUCTION FACTORS                :      -                  -
ADDITION MOMENTS (Maz and May)          :      -                  -

TOTAL DESIGN MOMENTS                    :    1345.74               45.15

REQD. STEEL AREA   :      8064.00 Sq.mm.
REQD. CONCRETE AREA:    621936.00 Sq.mm.
MAIN REINFORCEMENT : Provide  28 - 20 dia. (1.40%,   8796.46 Sq.mm.)
                     (Equally distributed)
TIE REINFORCEMENT  : Provide  8 mm dia. rectangular ties @ 300 mm c/c

SECTION CAPACITY BASED ON REINFORCEMENT REQUIRED (KNS-MET)
----------------------------------------------------------
Puz :  11420.14   Muz1 :   1463.50   Muy1 :    782.81

INTERACTION RATIO: 0.98 (as per Cl. 39.6, IS456:2000)

SECTION CAPACITY BASED ON REINFORCEMENT PROVIDED (KNS-MET)
----------------------------------------------------------
WORST LOAD CASE:   210
END JOINT:   229 Puz :  11684.92   Muz :   1595.62   Muy :    856.19   IR: 0.90
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Fig-7. Design output for the column considering signed response spectrum results

6. Findings from Present Case Study

Instead of using the usual process, designers can use the Signed Response Spectrum results. Designers can use the relevant command to instruct the program to use the sign of the member forces in Response Spectrum results for the most dominant mode - where the mass participation is the highest among all the considered modes in the analysis. If engineers use simple algebraic summation of the signed response spectrum quantities with the other load cases, the final result used for the design will have the proper sign. This can be simply understood from the output results of the case study. Designers can clearly identify the nature of forces in the column. In this process, designers are not changing the magnitude of Response Spectrum responses but are getting a realistic result that can be used in design.

7. Conclusion

Direct use of unsigned Response Spectrum analysis results in design sometimes leads to very erroneous design. Specifically, the corner columns of the building may experience very high tension arising from a load combination where the Response Spectrum load case is involved. It can be concluded from this case study that use of signed response spectrum results, where the sign of the response spectrum quantities obtained from the dominant mode, provides a realistic design result.

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