BEHAVIORAL ASPECT OF STEEL BRACING AS SEISMIC RETROFITTING ELEMENT.

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ABSTRACT-- *The earthquake at Bhuj, Gujarat, in 2001 has been a watershed event in the earthquake engineering practice in India. The techniques of earthquake prediction are still elusive. The code of practice for seismic analysis (IS 1893 Part 1: 2002[13]) has been revised to reflect the increased seismic demand in many parts of the country. Many existing buildings lack the seismic strength and detailing requirements of IS 1893 (Part 1): 2002[13], IS 4326:1993 and IS 13920:1993 [14], because they were built prior to the implementation of these codes. The theses work introduces the methodology to assess the seismic vulnerability of reinforced concrete (RC) buildings, lists the observed deficiencies and summaries the retrofit measures for the structurally deficient buildings the building categories addressed of are three- to ten-storied, residential and commercial buildings. The process of seismic evaluation and retrofit is a risk-reduction process. To identify the areas of seismic deficiencies in the building under investigation, the seismic evaluation of the building as per the condition and the available drawings and details of existing building is required to be carried out. The seismic evaluation of the earthquake affected building and the building which is not affected by earthquake but due to change in the codal provision it is required to be strengthened for the probable future earthquakes differ from each other. Based on the seismic evaluation of the building, various retrofitting methods can be suggested. The economy and the effectiveness of the methods should be studied.*

I. INTRODUCTION

In this topic a selected RC building is strengthened by new steel bracing for enhancing the lateral load resisting capacity [24]. It was found in Chapter-4 that the building is not capable to sustain the expected design force. For retrofitting the existing build new Steel Bracing is provided at the ground level. For finding the economic location of the Steel Bracing it is oriented in different way with different number of Steel Bracing. Total 5 different cases for orientation of the Steel Bracing is considered. Evaluation of each case is done for finding out the Performance Index. The recommended location of the Steel bracing is the one that enhances the lateral resistance with lower performance index & lesser number of Steel bracings. The Steel bracing is designed using a SEREB programme using the analysis results of SAP 2000 [06].

All different cases for location of Steel Bracing are explained below in detail.

II. ADDITION OF STEEL BRACINGS

Case- I Modelling of Steel Bracings

In this case Steel Bracing is located at all four corners as shown in Fig- 1 for identifying the location of Steel Bracing it is logically named as Ci-Bj. where C is for case and B is for Steel Bracing while i and j is integer number for case number and Steel Bracing number respectively. For example C1-B4 indicates the fourth number Steel Bracing for Case one.

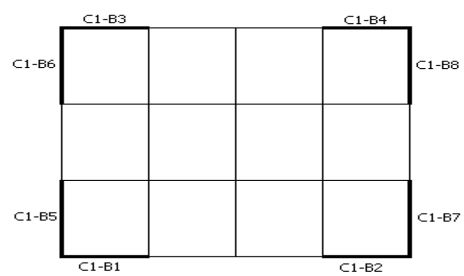

Fig- 1 Location of Steel Bracings for Case-1

For finding out the performance index of the upgraded building the building is modelled in SAP-2000. The procedure of the analysis is same as the evaluation procedure explained in chpter-4 excluding the modelling of Steel Bracing. Modelling of building is shown in Fig- 2

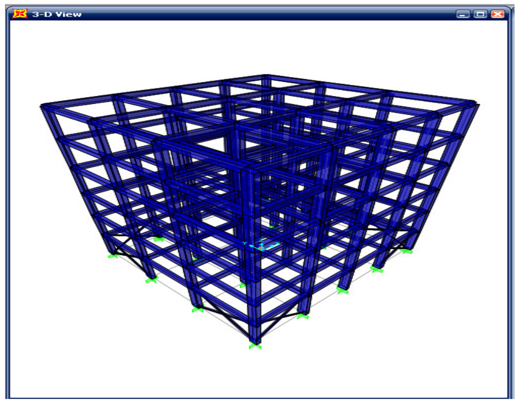

Fig- 2 : Modelling of Updated Building Case-1 Steel Bracing [06]

III. ANALYSIS OF RETROFITTED BUILDIND

After doing the modelling of the updated building Non-linear static pushover analysis performed in SAP 2000 and status of hinge in each element is find out for calculating the performance index.

IV. PERFORMANCE OF BUILDING AFTER ADDITION OF STEEL BRACINGS

Status of hinge after performing the nonlinear analysis is listed in Table- 1 performance index is calculated as explain bellow in tabular form

TABLE I

CALCULATION OF PERFORMANCE INDEX FOR CASE-1 STEEL BRACINGS

Hinge Status	**(X_i)**	**N_i^c**	**N_i^b**	**$1.5N_i^c$ (X_i)**	**N_i^b (X_i)**
A – B	0	162	184	0	0
B – IO	0.125	31	123	5.81	15.3
IO – LS	0.375	48	52	27	19.5
LS – CP	0.625	0	12	0	7.5
CP - C	0.875	0	0	0	0
>C	1	0	0	0	0
TOTAL	-	241	371	32.81	42.38

$$VI_{bldg} = \frac{1.5\sum N_i^{\,c} x_i + \sum N_i^{\,b} x_i}{\sum N_i^{\,c} + \sum N_i^{\,b}}$$

$= 0.1229$

Hence the performance index for Case- 1 is 0.1229

Repetitive modelling, analysis and performance index calculation is performed for the rest cases as explained bellow.

Case- 2

In this case Steel Bracings is located at the central bay of all outer frames only in the periphery frames as shown in Fig- 3

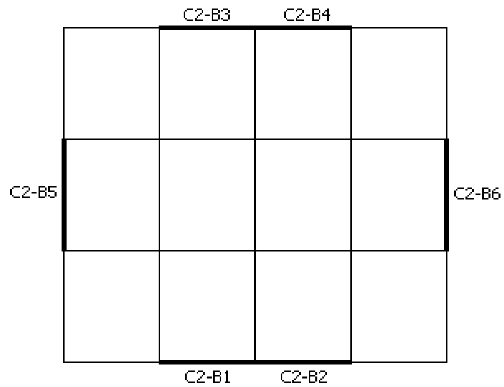

FIG- 3 : LOCATION OF STEEL BRACINGS FOR CASE-1

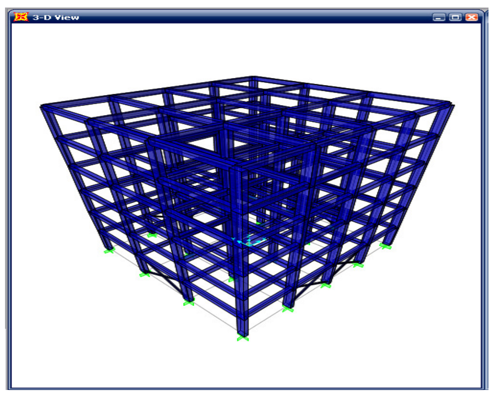

FIG- 4 : MODELLING OF UPDATED BUILDING CASE-2 STEEL BRACINGS [06]

Same as case -1 existing building updated with above location of steel bracing and modelled in SAP 2000 as shown in Fig- 4. Nonlinear static pushover analysis is performed after modelling of the building.

TABLE II

CALCULATION OF PERFORMANCE INDEX FOR CASE-II STEEL BRACING

Hinge Status	**(X_i)**	**N_i^c**	**N_i^b**	**$1.5N_i^c$ (X_i)**	**N_i^b (X_i)**
A – B	0	164	180	0	0
B – IO	0.125	31	111	5.81	13.88
IO – LS	0.375	46	68	25.87	25.5
LS – CP	0.625	0	12	0	7.5
CP - C	0.875	0	0	0	0
>C	1	0	0	0	0
TOTAL	-	241	371	31.67	46.88

After performing the analysis hinge status in each member is listed in Table- 2 along with the calculation of performance index.

$$VI_{bldg} = \frac{1.5\sum N_i^{\,c} x_i + \sum N_i^{\,b} x_i}{\sum N_i^{\,c} + \sum N_i^{\,b}}$$

= 0.1284

Hence the performance index for case- 2 is 0.1284

Case- 3

In this case steel bracing is located at the all four corner in staggered direction as shown in Fig- 5**.** Same as case -1 existing building updated with above location of steel bracing and modelled in SAP 2000 as shown in Fig- 6. Nonlinear static pushover analysis is performed after modelling of the building.

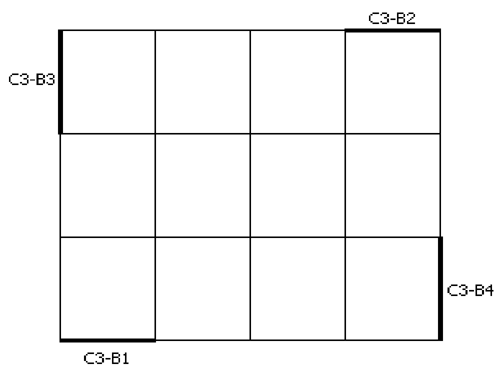

FIG- 5
LOCATION OF STEEL BRACING FOR CASE-3

After performing the analysis hinge status in each member is listed in Table- 3 along with the calculation of performance index.

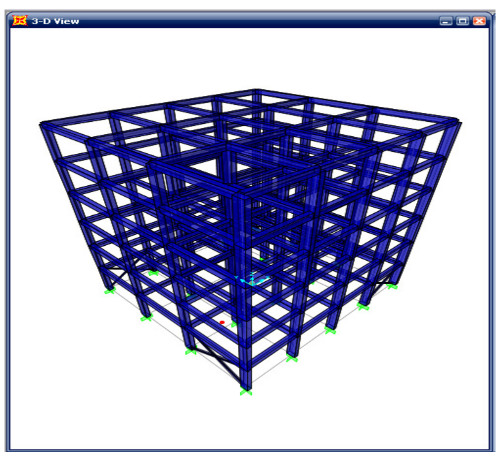

FIG- 6 : Modelling of Updated Building Case-3 Steel Bracing [06]

TABLE III
CALCULATION OF PERFORMANCE INDEX FOR CASE-III STEEL BRACING

Hinge Status	**(X_i)**	**N_i^c**	**N_i^b**	**$1.5N_i^c$ (X_i)**	**N_i^b (X_i)**
A – B	0	162	182	0	0
B – IO	0.125	23	111	4.31	13.88
IO – LS	0.375	56	66	31.5	24.75
LS – CP	0.625	0	12	0	7.5
CP - C	0.875	0	0	0	0
>C	1	0	0	0	0
TOTAL	-	241	371	35.81	46.13

$$VI_{bldg} = \frac{1.5\sum N_i{}^c x_i + \sum N_i{}^b x_i}{\sum N_i{}^c + \sum N_i{}^b}$$

= 0.1339

Hence the performance index for case- 3 is 0.1339

Case- 4

In this case steel bracing is located in the central bay of 3 bay frames and in the outer bay of the 4 bay frames only in the periphery frames as shown in Fig- 7

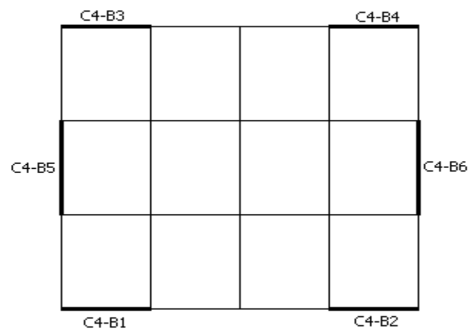

FIG- 7 : LOCATION OF STEEL BRACING FOR CASE-4

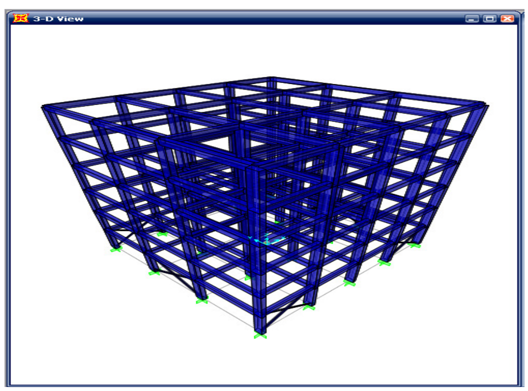

FIG- 8 : Modelling of Updated Building Case-4 Steel Bracing [06]

Same as case -1 existing building updated with above location of steel bracing and modelled in SAP 2000 as shown in **Fig- 8**. Nonlinear static pushover analysis is performed after modelling of the building.

TABLE IV
CALCULATION OF PERFORMANCE INDEX FOR CASE-IV STEEL BRACING

Hinge Status	**(X_i)**	**N_i^c**	**N_i^b**	**$1.5N_i^c$ (X_i)**	**N_i^b (X_i)**
A – B	0	162	180	0	0
B – IO	0.125	33	111	6.19	13.88
IO – LS	0.375	46	68	25.87	25.5
LS – CP	0.625	2	21	0	7.5
CP - C	0.875	0	0	0	0
>C	1	0	0	0	0
TOTAL	-	241	371	32.06	46.88

After performing the analysis hinge status in each member is listed in **Table- 4** along with the calculation of Performance index.

$$VI_{bldg} = \frac{1.5\sum N_i^{c} x_i + \sum N_i^{b} x_i}{\sum N_i^{c} + \sum N_i^{b}}$$

$= 0.1290$

Hence the performance index for case- 4 is 0.1290

Case- 5

In this case steel bracing is located in the outer bay of the 3 bay frames only in the periphery frames as shown in Fig- 9.

Same as case -1 existing building updated with above location of steel bracing and modelled in SAP 2000 as shown in Fig- 10. Nonlinear static pushover analysis is performed after modelling of the building.
After performing the analysis hinge status in each member is listed in Table- 5 along with the calculation of Performance index.

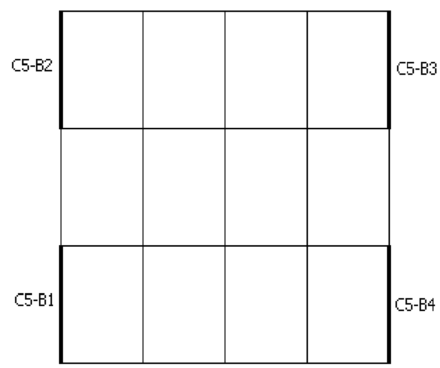

FIG- 9 : Location Of Steel Bracing For Case-5

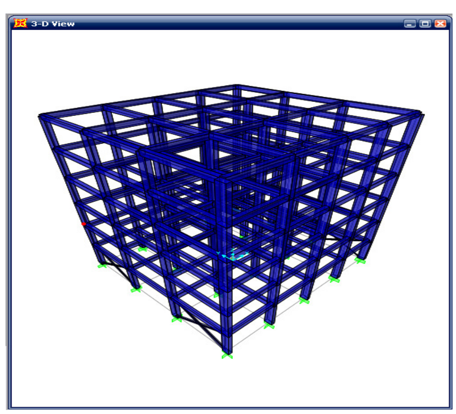

FIG- 10 : Modelling of Updated Building Case-5 Steel Bracing [06]

TABLE V : Calculation of Performance Index For Case-v Steel Bracing

Hinge Status	(X_i)	N_i^c	N_i^b	$1.5N_i^c (X_i)$	$N_i^b (X_i)$
A – B	0	133	251	0	0
B – IO	0.125	8	70	1.50	8.75
IO – LS	0.375	84	34	47.25	12.75
LS – CP	0.625	16	16	0	10
CP - C	0.875	0	0	0	0
>C	1	0	0	0	0
TOTAL	-	241	371	63.75	31.50

$$VI_{bldg} = \frac{1.5\sum N_i^{\,c} x_i + \sum N_i^{\,b} x_i}{\sum N_i^{\,c} + \sum N_i^{\,b}}$$

= 0.1556

Hence the performance index for case- 5 is 0.1556. Now, if Steel Bracing are provided gradually up to terrace level in all above cases following performance index are found (Table- 6). The procedure of analysis is same as above.

TABLE VI : Performance Index for Steel Bracing System

Hinge Status	Case I	Case II	Case III	Case IV	Case V
At soft story	0.1229	0.1284	0.1339	0.1290	0.1556
up to 2nd floor	0.0643	0.0683	0.0680	0.0661	0.1440
up to 3rd floor	0.0217	0.0311	0.0313	0.0311	0.1299
up to 4th floor	0.0086	0.0177	0.0141	0.0169	0.1275
up to 5th floor	0.0033	0.0140	0.0135	0.0140	0.1252
up to 6th floor	0.0012	0.0118	0.0114	0.0118	0.1211

Table 6 shows that when the steel bracings are provided gradually up to terrace level, performance index is reduced simultaneously. It also shows that Case-3 (at all four corners in staggered position) has minimum performance index with least number of steel bracing, hence the storey drift at each floor level for Case-3 was found and it is shown in Table- 6.7. Governing roof displacement at terrace level is 0.063m and 0.004m in X and Y direction respectively.

TABLE VII

PERFORMANCE INDEX FOR STEEL BRACING SYSTEM

Story No.	Story Drift (mm) in X-direction					
	1st	2nd	3rd	4th	5th	6th
1	3.475	3.039	3.166	3.235	3.273	3.283
2	14.431	4.138	3.989	4.218	4.336	4.364
3	18.709	12.301	4.398	4.433	4.649	4.697
4	13.812	11.730	9.200	4.480	4.564	4.640
5	8.343	8.196	7.990	6.950	4.122	4.150
Terrace	4.598	4.615	4.626	4.573	4.010	3.176

TABLE VIII : Performance Index for Steel Bracing System

Story No.	Story Drift (mm) in X-direction					
	1st	2nd	3rd	4th	5th	6th
1	0.165	0.090	0.104	0.111	0.115	0.117
2	0.856	0.107	0.058	0.083	0.097	0.102
3	1.127	0.747	0.041	0.019	0.043	0.053
4	1.054	0.937	0.527	0.002	0.013	0.004
5	0.770	0.717	0.567	0.333	0.042	0.051
Terrace	0.438	0.413	0.357	0.286	0.147	0.117

Storey drift and roof displacement for Strengthened building is within the permissible range 0.012m and 0.072m, (excluding soft storey location).

V. SUMMARY

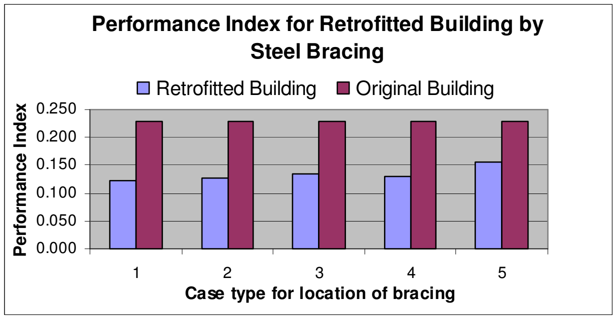

FIG- 11 : Comparison of Different Cases of Steel Bracing With Original Building

VI. CONCLUSIONS

1. If the steel bracing is provided at only soft story, from the above calculation it was found that the strengthened building (for all the 5 cases) has lower performance index [4] than the original building. Excluding the case-5 all have performance index is lower than the expected performance index of 0.125. However case-3 has performance index is lower than the expected performance index of 0.125 with less number of Steel Bracings which shows that if the building is retrofitted with the case-4 will sustain the expected design earth quake forces.
2. Story drift exceeds the limiting value when provided only at soft storeylevel. If at all it is provided throughout the height of the building storey drift for he building can be reduced.
3. It the bracing retained at intermediate floor level it leads to change in vertical stiffness between two floors. Hence to avoid this phenomenon it is recommended that , for global retrofitting strategies bracing should be provided up to terrace level.

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