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Comparing the Seismic Behavior of Special Truss Moment Frames at Near-Fault and Far-Fault Points

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ABSTRACT

In bending buildings with large openings, using beams as load bearing trusses is going to be regarded as one of the main design choices due to the economic characteristics as well as being simple to connect to the columns, being lighter, open truss webs making better use of space providing better facilities for passing pipes, which results in stories with lower heights. Besides these advantages, these structures have important disadvantages. Due to the way of building, the beams have more hardness and resistance than columns. In such structures under earthquake, there is the possibility of formation of plastic hinge in columns, which is not good according to engineers. Also, due to premature buckling of the web members under horizontal reciprocating loads, a sharp drop in the hysteresis graph of these systems is observed which indicates a very low energy absorption in these systems and the hysteresis graph of these systems is unstable. Recently a new type of truss is proposed in which the plastic hinge location is in the central part of truss and also their hysteresis graphs are more stable, these frames are named “special truss moment frames”. And also The different behavior of structures and heavy losses in four quakes; Northridge1994 (California) ,Kobe 1995) Japan, Duzce (1999) Turkey, Chi-Chi (1999) Taiwan, especially in the structures located on the path leading to the rupture, has made clearly evident the significance of paying utmost attention to the near-fault records. This study was designed to compare the seismic behavior of special truss moment frames at near-fault and far-fault points. For this purpose, a non-linear static analysis method and non-linear dynamic time history is used.
1, 3 and 5 storey structures, designed using Iran’s 2800 code and ubc97, have been studied in this research. Plastic hinges are considered for these structures according to FEMA-356 Criteria and selected records (Two horizontal components and a vertical component) are based on the soil type and the scale is 5% damping. Analysis was performed using the program Sap2000 for all three structures.
KEYWORDS: special truss moment frames; near-fault; nonlinear dynamic analysis.

1. INTRODUCTION

In the method of designing based on the performance, the three terms of performance, capacity, and need are to be considered. Need is indicative of the earthquake motion and capacity shows the resistance of structures against the earthquake motion. Performance is the state when capacity is able to cater for the need. In the performance-based seismic design of structures for different levels of expected performance different levels of earthquake are designed. To achieve this goal, we used a non-linear analysis.

2. Non-linear dynamic analysis

Step by step integration method is the most effective method for nonlinear analysis of structures. In this way, the system’s responds are calculated in a sequential series of steps of short time intervals t_{Δ} which are considered the same in order to facilitate the computation. Dynamic equilibrium condition was applied at the beginning and end of each time interval and

The system movement during each step is roughly evaluated based on a hypothetical mechanism of response. Inelastic nature of the system is considered through calculating the new properties corresponding to deformed state at the beginning of each time step. A complete response is achieved through calculating the velocity and displacement at the end of each arithmetic interval and using them as initial conditions for the next interval. Also, at the end of each interval, the system characteristics (stiffness and damping, etc.) are amended tailored to the reshaping situation at the moment. Inelastic analysis turns into a range of analysis of elastic systems which are constantly changing.

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The equation of motion of a multi-degree of freedom system at any moment for inelastic response is expressed as follows:

[M]δ{ừr}+ [C]δ{ůr}+ [K] δ{ŭr}=- [M]δ{ừg}t

Where [M] is matrix mass system, [C] is damping matrix , [K] tangent stiffness matrix at any moment of time, δ {ừg} t is Ground motion acceleration vector at any moment of time, δ {ừr}, δ {ůr}, δ {ŭr} are displacement, velocity and acceleration changes vectors respectively." Seismosignal Help Manual, Seismosignal ver.3-3-0."

3. Special truss moment frames with beams

In Special truss moment frames with beams, the energy absorbing and plastic deformation region is at the central region of the truss. In this area (special area), there is a low-cut vertical load and by putting weaker diagonal members or even removing these members, the area can be prone to inelastic deformation and seismic energy absorption. Some studies show that special truss, in addition to having appropriate mechanisms for seismic regions, it also brings about some savings in steel consumption. Special trusses can be designed as x-diagonals or the central part as rectangular openings (Vierendeel)." Goel,S. C.,and Itani,1994" The submission mechanism of these kind of trusses are shown in figures (1) and (2).

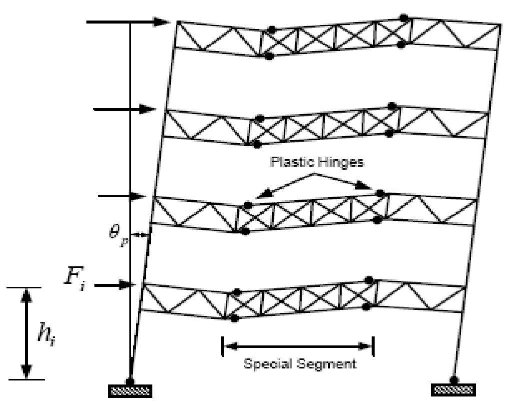

Figure 1. Frame with special truss beam (x-diagonals)

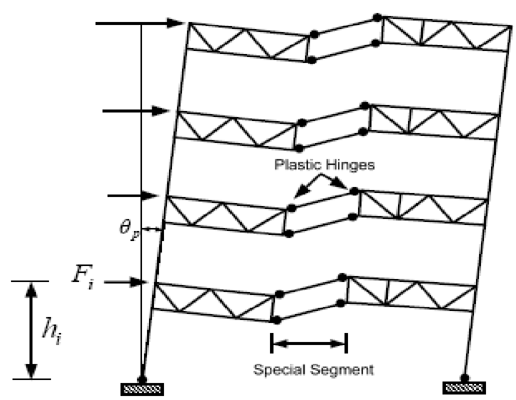

Figure 2: frame without special truss beam (Vierendeel)

4. Controlling regulations in terms of rigid truss frames

To establish the expected mechanism in Special truss moment frame structures with beams, some regulations are provided by ubc 97 code which are as follows: ". UBC, Uniform Building Code, 1997"

1 - Special part should have a length of .5 to .1 times as big as the length of the truss and be placed at center of opening.

2 - The aspect ratio of each panel in special part, the ratio of length to height, should be between 2.3 and 3.2.

3 - If it is to apply double-sided diagonals, these diagonals should be connected in the middle of the opening and in all panels vertical members are to be used.

4 - The connection between two diagonals should be designed for 25% of the tensile strength of diagonal and using screw connection in special part is prohibited.

5 – Patching horizontal edges, especially in special part and also in half the distance between special part and column is not acceptable.

6 - Axial stress in diagonal members due to dead and live loads shall be no more than .03fy. This limit is for the special part to be used throughout its length.

7 - The purpose of the special truss rigid frames is horizontal edges to flow in bending and diagonals in tension or pressure. For horizontal edges to flow in bending, the axial force should be limited in them. For this reason, the maximum axial stress in the horizontal members should not be larger than .4.

5. Near-fault and far-fault earthquakes of this study

In section 2-4-1-4 of the 2800 code is referred to the number of accelerograms which goes:

The accelerograms used in determining the motion of the earth, should represent the actual movement of the ground at the construction site during an earthquake.

For this purpose, it is necessary that at least three pairs of accelerograms belonging to horizontal components of three different earthquake be recorded which their impact should be on the structure.

Also in FEMA356 Code, the words (at least three pairs of horizontal accelerograms) are discussed.

In this study, to investigate and apply near-fault conditions five earthquakes are selected. The conditions of accelerograph stations and soil type are identical in all five earthquakes So that in addition to having close to the epicenter of the earthquake, they are located on the path leading to the rupture fault. The accelerograph of the earthquake in Bam, Tabas, Balm, Loma and Northridge are used in this research.

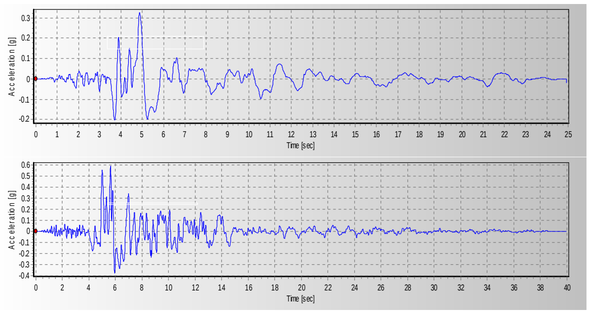

Figure 3. Diagram of the horizontal component of earthquake Accelerogram Northrige (near- fault)

6. Selecting the distance from the fault

Near-fault zone is the area which is close to the epicenter. The observed range of 15 km from the epicenter is considered as near-fault area. In applying the term near-fault for the accelerograms registered in this area, it should be considered that in addition to studying the Accelerometer station distance, the position of the station relative to the rupture of the fault is important too, because due to the properties of the resulting shear waves from earthquakes and accumulation of effects, most of the shear waves are observed in front of the rupture path.

7. Scaling accelerogram pairs

To read and draw the accelerogram of selected earthquake for dynamic analysis and also scaling accelerogram pairs, the software Seismosignalver3-3-0 is used.

In accordance with part (2-4-1-4-2 - Z) of 2800 Code "Iranian code of practice for seimic resistant design of buildings (third edition), 1384" all Accelerogram should be the maximum of their scale. This means that the maximum acceleration of all of them should equal the acceleration g.

Each earthquake in horizontal line has two Accelerograms, one at axes X and the other at Y axes of the structure, for each of these Accelerograms a separate response spectra is plotted. In accordance with part (2-4-1-4-2 - c) "Iranian code of practice for seismic resistant design of buildings (third edition), 1384" to develop a range of responses for each pair of Accelerogram, the response spectra of the Accelerogram in each direction are combined using the square root of the sum of squares. The resulting spectra are averaged and the resulting average spectrum is used as the spectrum to calculate the scale factor.

The scale factor is the number which should be in the range of T2 / 0 to T5 / 1 to satisfy part (2-4-1-4-2 - d) "Iranian code of practice for seismic resistant design of buildings (third edition), 1384" with a range of standard designs and the average values of this range should not be in any case less than 1/4 times as much as it is in the standard range. (T is the main period of building, which is derived from empirical relations).

Now the obtained number, scale factor, should be multiplied by all scaled accelerograms and then the modified re-combined spectrum should be obtained for each earthquake. In Dynamic analysis of the structures, these Accelerograms should be used.

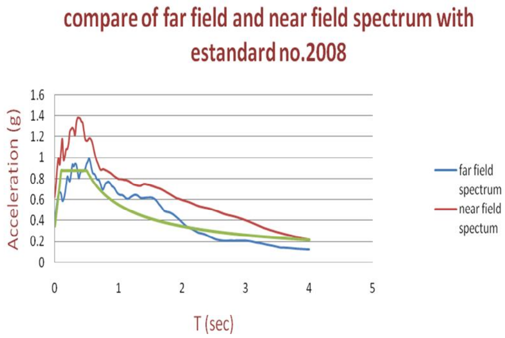

Figure 4. Comparing near-and far-fault spectrum and 2800 Code spectrum

8. Nonlinear dynamic analysis

In nonlinear dynamic analysis we have used a step by step integral with the assumption of a linear accelerator the most important factor in nonlinear dynamic analysis is behavior of the members curve and used Accelerograms.

In nonlinear dynamic analysis with the method of time history, the nonlinear response of the structure will change depending on the type of accelerograms.

To do so, it is better to use as many accelerograms as possible. As noted above, according to FEMA-356, it is necessary to use at least three records for analyzing.

9. Definitions of basic models

In order to compare the results of designing steel buildings with the system of special truss moment frame design based on UBC-ASD97 Code and evaluation based on the performance of the assumed structures based on FEMA-356 Code, 3 models in 1, 3 and 5 floors are made.

- The size of the opening at direction as the beam truss span is 14 meters.
- User-specified commercial buildings.
- The height of all stories is 5 meters.
- The soil of the site is type 2 according to the classification of 2800 Code.
- The site is located in a region with very high risk.

As for modeling, analysis and initial design of the assumed models, Etabs ver.9.5 software is used.

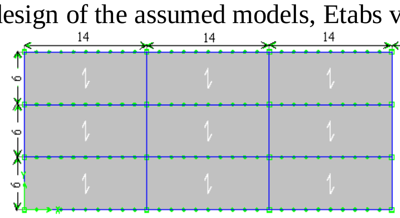

Figure 5. Plan of building (dimensions in meters)

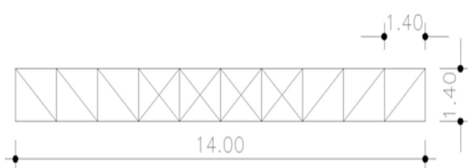

Figure 6. Form of truss beam (dimensions in meters)

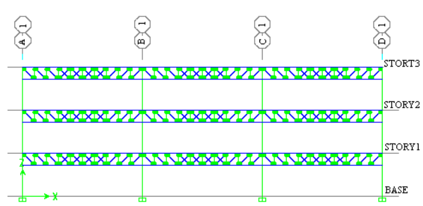

Figure 7. A View of 3-storey frame (dimensions in meters)

10. Checking the base cut off near the earthquake fault to far-fault structures

In order to better compare the results, Cut-off values based on the values of near-fault accelerograms divided by far-fault accelerograms are considered the same and the resulting ratio is presented in the following charts.

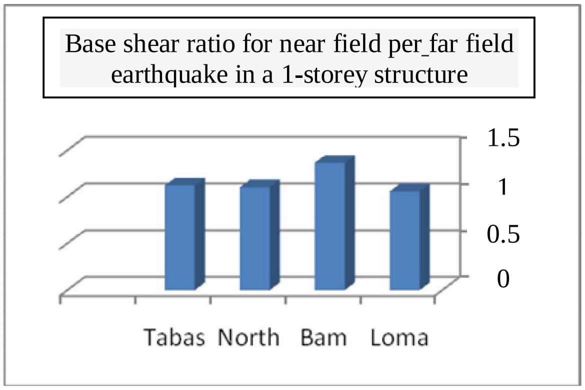

Figure 8. Base shear ratio for near field per far field earthquake in a 1-storey structure

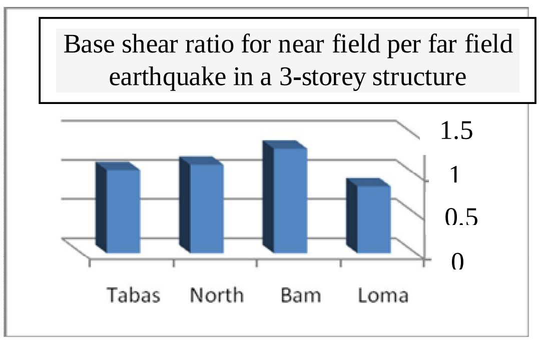

Figure 9. Base shear ratio for near field per far field earthquake in a 3-storey structure

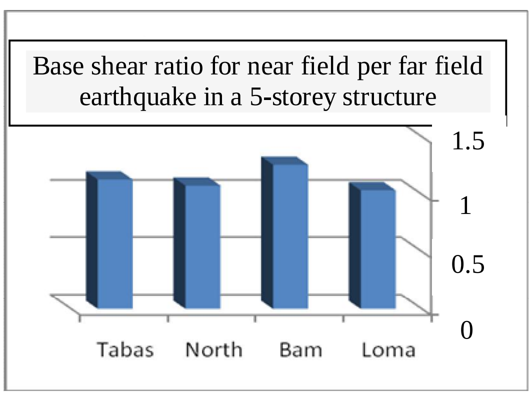

Figure 10. Base shear ratio for near field per far field earthquake in a 5-storey structure

11. Comparing the maximum displacement of the roof structure and columns' axial force.

In this study, with the purpose of comparing the response of structures under earthquake near and far fault, the displacement of the roof structure and columns' axial force are as follows:

Table 1. Maximum roof displacement and column axial force in 1 story structure

Number of story	***Earth quake***	**component**	**Maximum displacement (cm)**	**Axial column force (ton)**
One story	Loma-Far	horizontal	1 ,37	38,63
One story	Loma-Near	horizontal	2,13	42,53
One story	bam-Far	horizontal	1,41	61,24
One story	bam-Near	horizontal	3,64	94,27
One story	Northridge-Far	horizontal	3,55	49,13
One story	Northridge-Near	horizontal	4,24	74,5
One story	Tabas-Far	horizontal	1,71	29,08
One story	Tabas-Near	horizontal	2,12	45,25
One story	Loma-Far	horizontal + vertical	1,85	45,94
One story	Loma-Near	horizontal + vertical	2,42	76,02
One story	Bam-Far	horizontal + vertical	2,37	57,43
One story	Bam-Near	horizontal + vertical	3,89	91,34
One story	Northridge-Far	horizontal + vertical	3,71	95,04
One story	Northridge-Near	horizontal + vertical	4,54	67,53
One story	Tabas-Far	horizontal + vertical	1,71	47,84
One story	Tabas-Near	horizontal + vertical	3,16	80,83

Table 2. Maximum roof displacement and column axial force in 3 story structure

Number of story	***Earthquake***	**component**	**Maximum displacement *(cm)***	**Axial column force*(ton)***
Three story	Loma-Far	horizontal	4,72	151,14
Three story	Loma-Near	horizontal	3,71	86,22
Three story	bam-Far	horizontal	3,28	76,85
Three story	bam-Near	horizontal	4,53	140,04
Three story	Northridge-Far	horizontal	5,46	205,38
Three story	Northridge-Near	horizontal	7,09	116,21
Three story	Tabas-Far	horizontal	3,57	226,36
Three story	Tabas-Near	horizontal	5,25	124,97
Three story	Loma-Far	horizontal + vertical	5,53	169,17
Three story	Loma-Near	horizontal + vertical	4,21	88,19
Three story	Bam-Far	horizontal + vertical	3,52	64,66
Three story	Bam-Near	horizontal + vertical	4,71	187,03
Three story	Northridge-Far	horizontal + vertical	5,92	213,56
Three story	Northridge-Near	horizontal + vertical	7,43	135,68
Three story	Tabas-Far	horizontal + vertical	3,94	221,65
Three story	Tabas-Near	horizontal + vertical	5,68	103,44

Table 3. Maximum roof displacement and column axial force in 5 story structure

Number of story	***Earthquake***	**component**	**Maximum displacement *(cm)***	**Axial column force*(ton)***
Five story	*Loma-Far*	horizontal	*7,52*	*165,82*
Five story	*Loma-Near*	horizontal	*9,26*	*330,34*
Five story	*bam-Far*	horizontal	*6,95*	*338,48*
Five story	*bam-Near*	horizontal	*7,14*	*281,54*
Five story	*Northridge-Far*	horizontal	*8,84*	*318,11*
Five story	*Northridge-Near*	horizontal	*10,33*	*420,56*
Five story	*Tabas-Far*	horizontal	*6,7*	*306,66*
Five story	*Tabas-Near*	horizontal	*8,14*	*300,2*
Five story	*Loma-Far*	horizontal + vertical	*7,84*	*136,94*
Five story	*Loma-Near*	horizontal + vertical	*9,51*	*370,82*
Five story	*Bam-Far*	horizontal + vertical	*7,21*	*386,58*
Five story	*Bam-Near*	horizontal + vertical	*8,62*	*548,32*
Five story	*Northridge-Far*	horizontal + vertical	*8,95*	*330*
Five story	*Northridge-Near*	horizontal + vertical	*10,71*	*395,81*
Five story	*Tabas-Far*	horizontal + vertical	*6,85*	*334,4*
Five story	*Tabas-Near*	horizontal + vertical	*8,53*	*298,91*

13. Determining the detailed terms of points

Noting that the behavior of three structures was bending, at the columns and horizontal members of truss for interaction of axial force and bending hinge P-M3 at diagonal and vertical of the truss pivot axis P has been allocated according to tables FEMA-356. The detailed terms of points of the structure are determined regarding near-fault and far-fault according to 2800 spectrum and finally, with regard to life safety performance LS, all three structures have been studied extensively and was seen that under the spectrum of far-fault the hinges have not passed life safety, but under the spectrum of near-fault, it has past life safety.

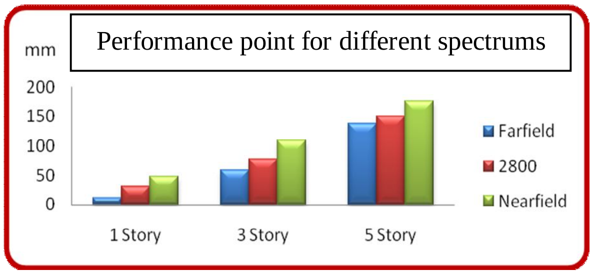

Figure 11. Comparing the performance in structures of STMF

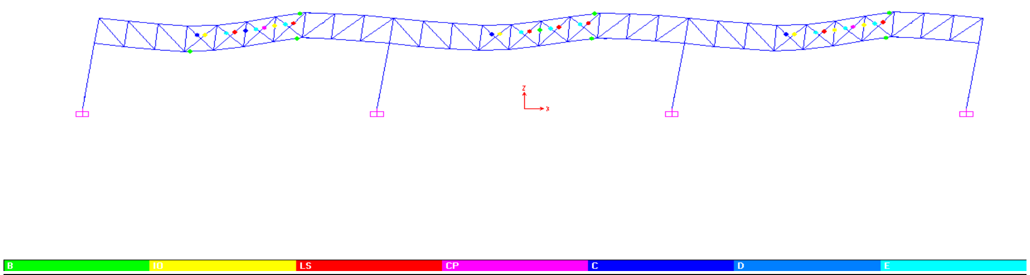

Figure 12. Hinge formation in one-story model STMF and their performance range (the range of the fault)

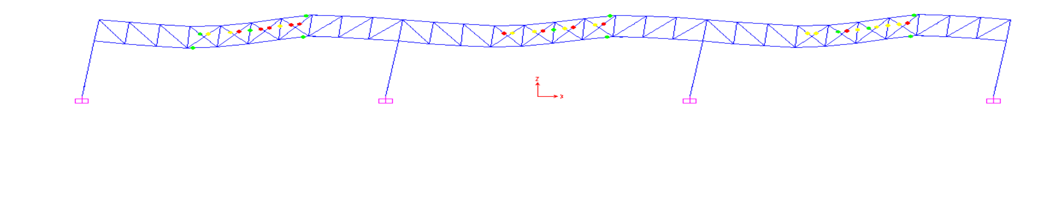

Figure 13. Hinge formation in one-story model STMF and their performance range (the far of the fault)

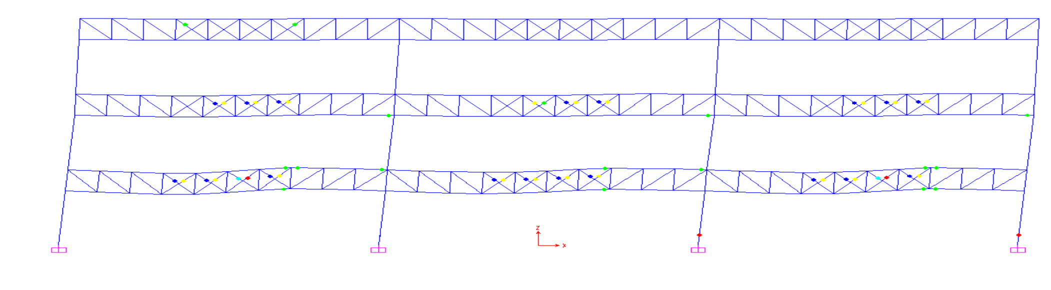

Figure 14. Hinge formation in three-story model STMF and their performance range (near field)

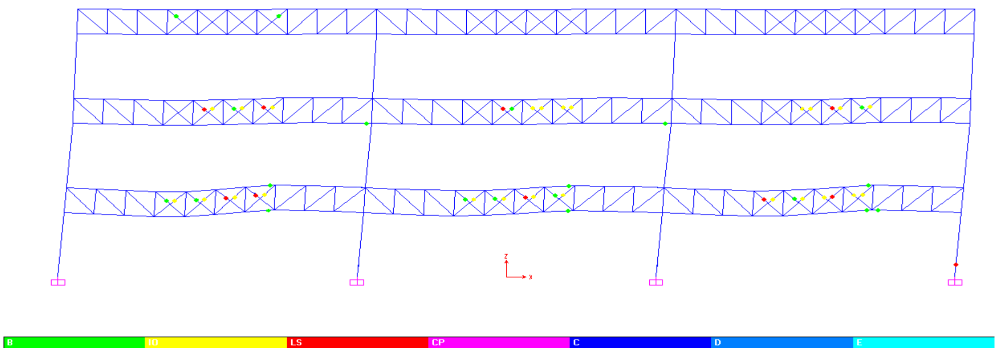

Figure 15. Hinge formation in three-story model STMF and their performance range (far field)

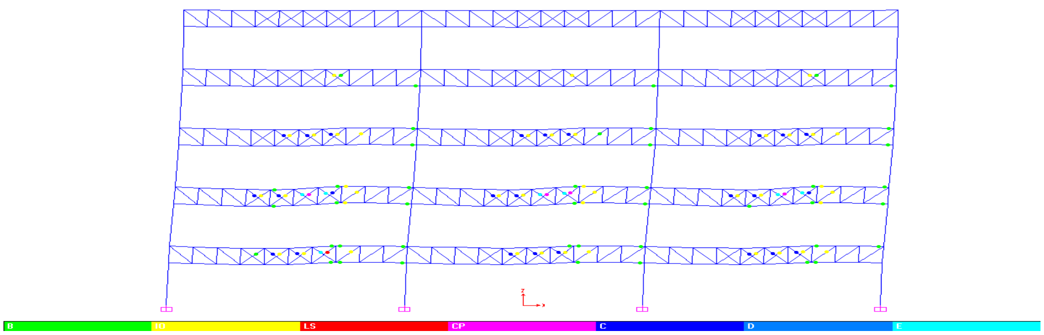

Figure 16. Hinge formation in five-story model STMF and their performance range (near field)

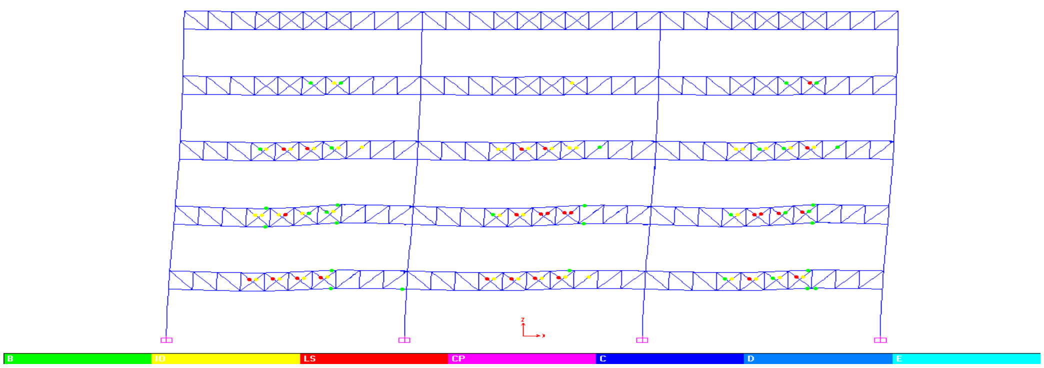

Figure 17. Hinge formation in five-story model STMF and their performance range (far field)

14. Conclusion

In the structures of this study, near fault area records generally have larger lateral displacement than far-fault area records, which it can be due to the specific characteristics of these records.

• comparing the base shear in the earthquakes near the fault with the base shear of the same earthquake in far-fault, it was observed that the base shear in near-fault area had 10 to 15 % increase.

• The Northridge earthquake accelerograms record is the most destructive used in the analysis. As this earthquake had several important pulses with different frequencies and high frequency content, it has had intense effects on all systems.

• In the investigated earthquakes, generally the vertical components near the faults have resulted in more compressive and tensile forces. The interesting point is the vertical components of Bam earthquake which are very famous. The records of vertical component near this earthquake have more severe central effects on structures under study.

• The performance of structures in near-fault areas is far greater than the value in the far-fault field.
• Due to observing the special regulations of designing in STMF structures, it is observed that the formation of plastic hinges in the structure is generally done in the special part.
• More Plastic hinges which have passed life safety are formed in structures under near-fault earthquakes.

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