# Seismic Performance of Steel Moment-Resisting Frames considering Partially Restrained Connections

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## 1. INTRODUCTION

The use of Steel Moment-Resisting Frames (SMRF) as seismic resistant structural system has been very used for the profession in the construction of steel buildings, being the high ductility capacity one of its advantages in comparison with other lateral resistant force structural systems. However, during the 1994 Northridge Earthquake occurred in California, significant structural damage was observed in several SMRF, including brittle fracturing starting in the connections. Furthermore, one year later in Japan, the Kobe Earthquake caused that more than 50 steel buildings collapsed. This situation prompted massive programs for research, generating important changes in building codes. These changes included the specification of prequalified connections which were able to provide an adequate cyclic inelastic behavior.

SMRF are typically analyzed assuming the connections fully restrained (FR). Additionally, SMRF are usually designed as plane frames resisting the total lateral seismic loading and ignoring the presence of interior gravity frames (IGF). These last are designed to resist only the gravity loads, and their connections are assumed to be perfectly pinned (PP).

Nevertheless, almost all connections used in real frames are essentially partially restrained (PR) and experimentally exhibit semi-rigid nonlinear response characteristics. All this implies that the connections modeled as FR posses some flexibility while those modeled as PP posses some rigidity. Flexible behavior of a connection is commonly described by the relationship between the moment "M", transmitted by the connection and the relative angle of rotation between the connecting members "θ", as shown in Figure 1. This has been widely investigated and reported in the literature (Gao and Haldar, 1995).

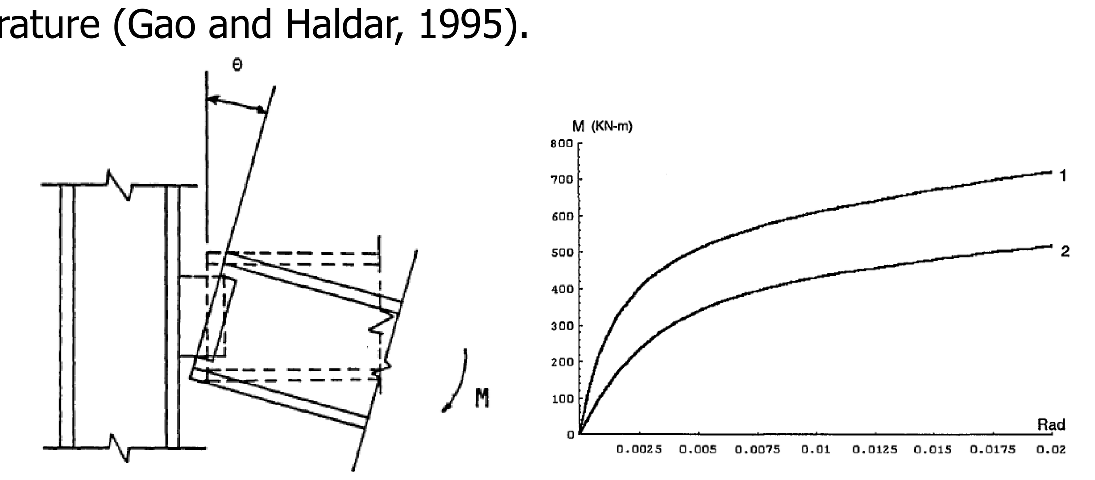



**Figure 1:** Moment and relative rotation of a connection (Gao, 1994).

Consequently, the purpose of this research is to study the behavior of SMRF considering these modeling aspects that are traditionally ignored, using a non commercial finite element software incorporating the nonlinearity of the structural model caused by the presence of PR connections. The program fit in the PR connections using the connection element approach, which is equivalent to add a rotational spring at the member's end for each PR connection. This element has a stiffness that need to be modified with respect to a moment-rotation curve obtained experimentally (Richard, 1993).

## 2. OBJECTIVES

- To compare the seismic response of SMRF designed with Pre and Post Northridge connections.
- To evaluate the effect of 3D modeling considering interior gravity frames and their connections.
- To check the differences in seismic response between the non commercial computer program used in this research and a commercial software of extensive and popular use (SAP2000).

## 3. METHODOLOGY

**1** Two structures were subjected to the 1994 Northridge Earthquake.

- ❑ Linear time history analysis.
- ❑ 2D + FR connections.
- ❑ 2 different software.

**2** Two structures were subjected to the 1994 Northridge Earthquake.

- ❑ Nonlinear time history analysis using 2D FR and 2D with Pre and Post Northridge connections.
- ❑ Non commercial software.

**3** 3-Story building was subject to 20 ground motions with different predominant periods.

- ❑ Nonlinear time history analysis using 3 different models:
  - ➢ 2D FR
  - ➢ 3D FR + IGF with PP connections
  - ➢ 3D FR + IGF with PR connections
- ❑ A total of 60 analysis in the non commercial software.

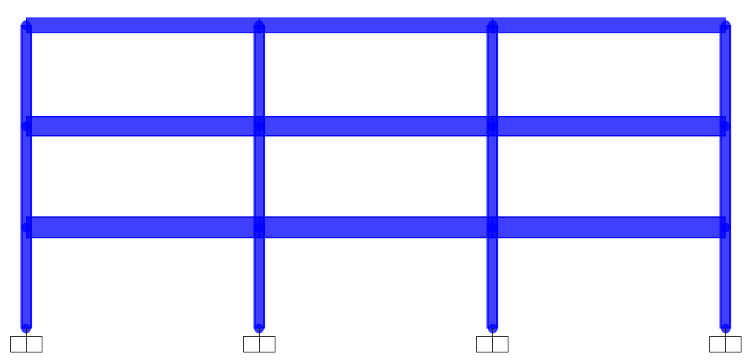


**Figure 2:** 2D 3-story building.

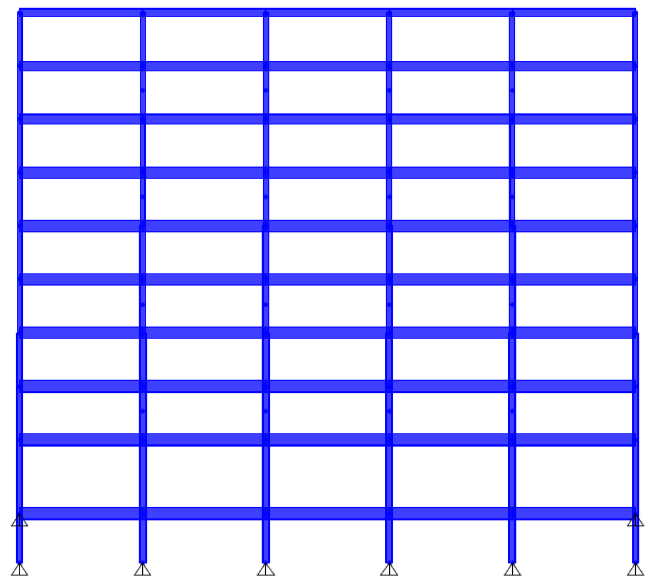


**Figure 3:** 2D 9-story building.

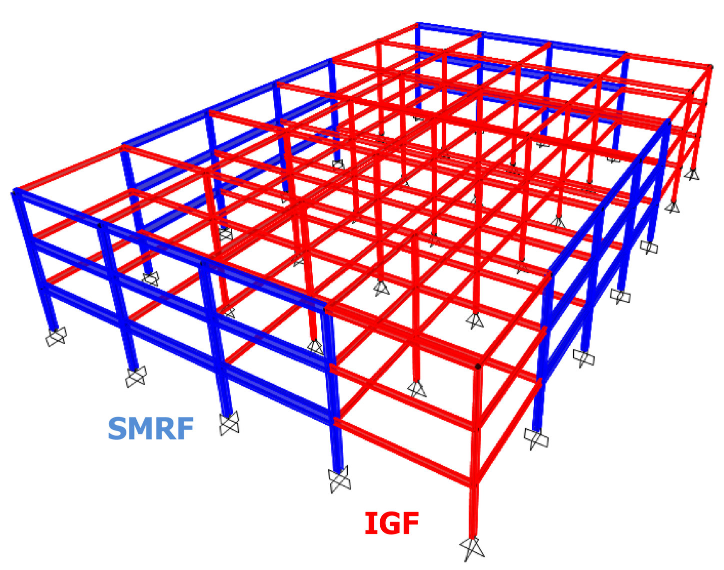


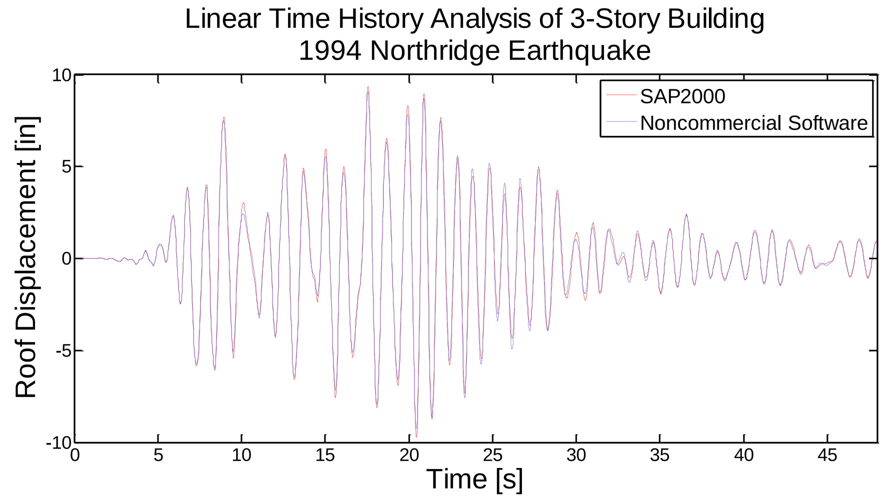

**Figure 4:** 3D 3-story building.

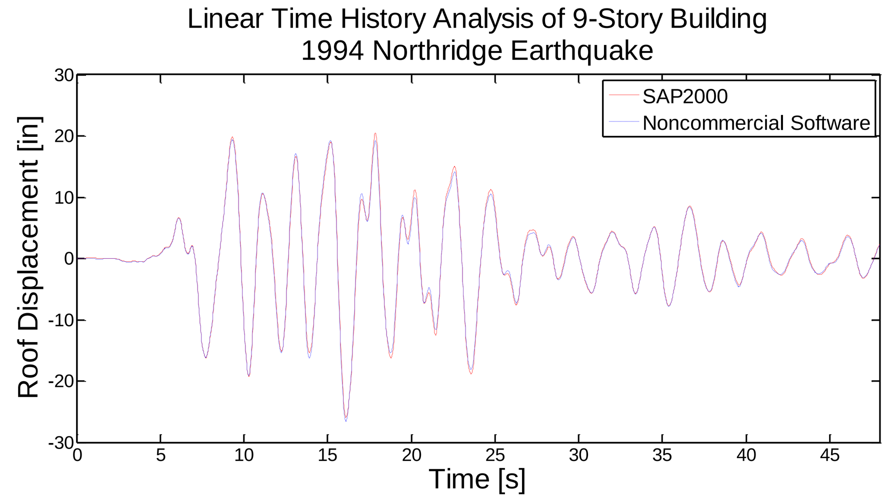
| SEISM | PLACE | YEAR | STATION NAME | T (sec) |
|---|---|---|---|---|
| 1 | México | 1985 | Paraíso | 0.13 |
| 2 | E.U.A. | 1980 | Convict Creek | 0.14 |
| 3 | México | 1985 | La Unión | 0.25 |
| 4 | Northridge | 1994 | Wadsworth V. A. | 0.25 |
| 5 | El Salvador | 2001 | Presa 15 de Septiembre | 0.28 |
| 6 | E.U.A. | 1980 | Mammoth H. S. | 0.29 |
| 7 | El Salvador | 2001 | Relaciones Exteriores | 0.31 |
| 8 | México | 1985 | Infiernillo N-120 | 0.32 |
| 9 | México | 1985 | Apatzingan | 0.38 |
| 10 | México | 1985 | Zihuatanejo | 0.38 |
| 11 | El Salvador | 2001 | Ciudadela Don Bosco | 0.41 |
| 12 | E.U.A. | 1980 | Long Valley Dam | 0.47 |
| 13 | E.U.A. | 2001 | Olimpia: DNR Building | 0.51 |
| 14 | Northridge | 1994 | Griffith Observat | 0.51 |
| 15 | El Salvador | 2001 | Relaciones Exteriores | 0.55 |
| 16 | México | 1985 | Villita | 0.55 |
| 17 | E.U.A. | 1984 | Halls Valley | 0.65 |
| 18 | El Centro | 1940 | Valle Imperial | 0.68 |
| 19 | E.U.A. | 2001 | Olympia, WSDOT | 0.69 |
| 20 | Alaska | 2002 | AK: R109 | 0.83 |

**Figure 5:** The 20 different ground motions used.

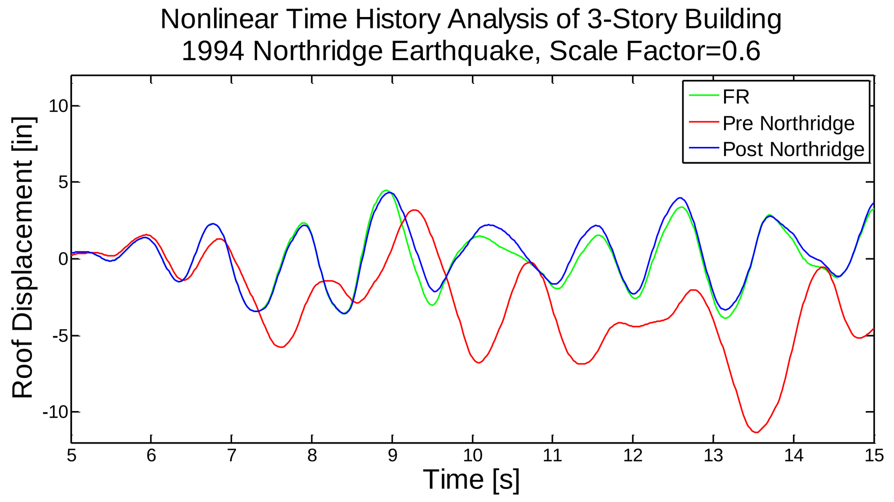
## 4. RESULTS

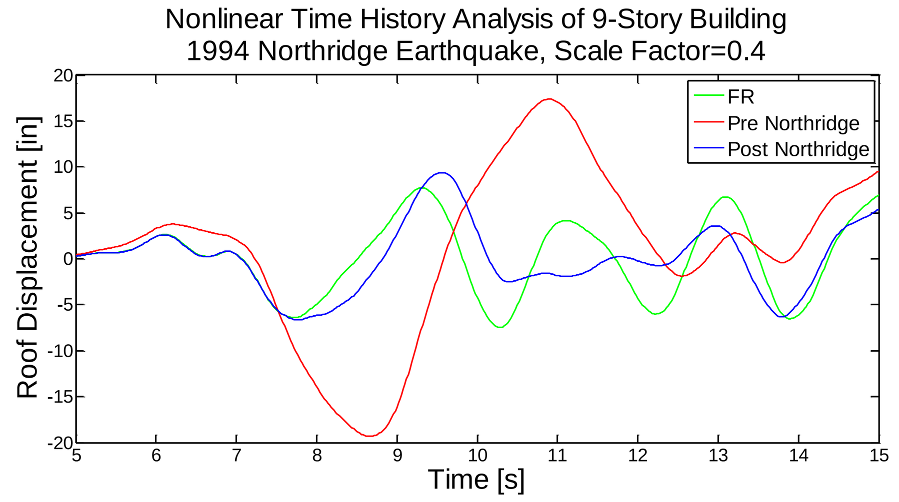
**1** **Noncommercial software vs SAP2000 – Linear Time History Analysis**



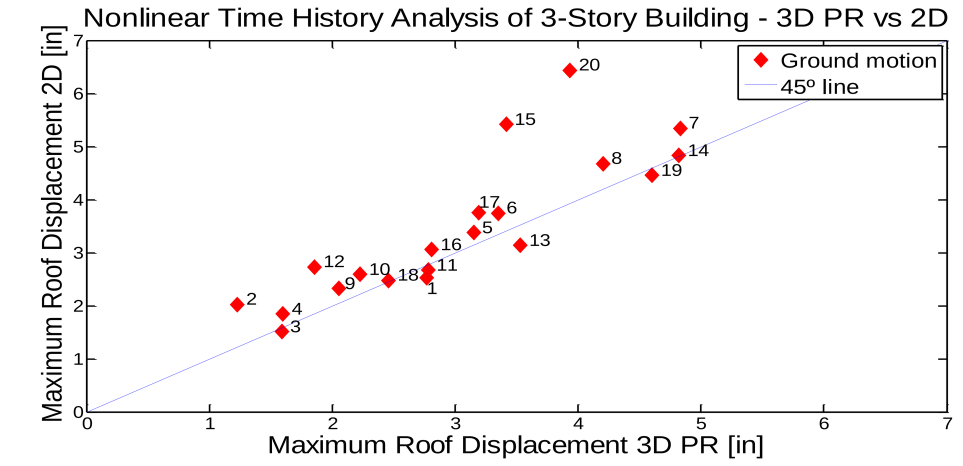

**2** **Pre vs Post Northridge Connections – Nonlinear Time History Analysis**

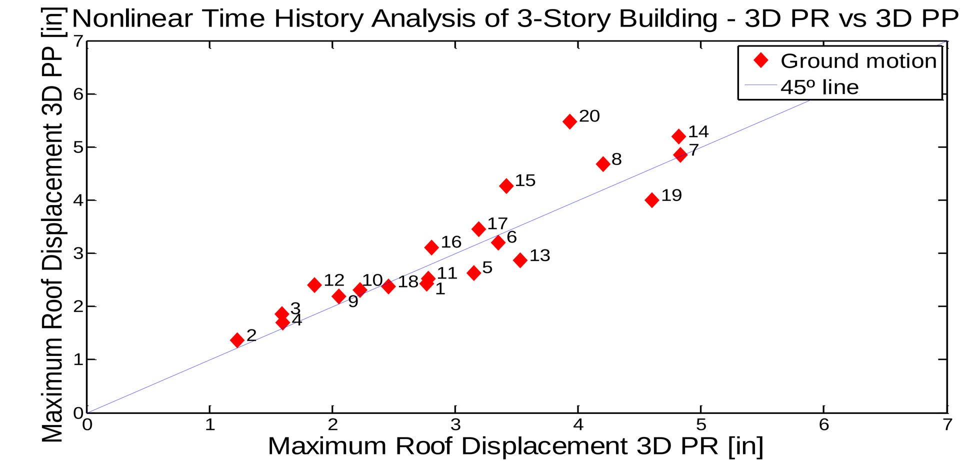



## 4. RESULTS

**3** **2D and 3D with interior gravity frames**




## 5. CONCLUSIONS

- The noncommercial software gives practically the same linear time history response than SAP2000 both in low and medium rise buildings. Therefore, the results provided by the software are strongly reliable.
- Modeling Pre Northridge connections as FR underestimates the actual roof displacement, and this can be much larger if the ground motion is strong.
- The Post Northridge connections provides a behavior much closer to FR than Pre Northridge connections, limiting the lateral roof displacement, producing beneficial effects on the buildings.
- To model the buildings as bi-dimensional frames neglecting the IGC and their PR connections produce, in general, bigger roof lateral displacement and may result in very conservative designs.
- To model the buildings in 3D considering the IGC but modeling their connections as PP, gives closer results that the 2D modeling, but none of them represents the real behavior of the structure.

## 6. REFERENCES

- Gao L., Haldar A. (1995). Nonlinear Seismic Analysis of Space Structures with Partially Restrained Connections. *Microcomputers in Civil Engineering* 10 27-37.
- Richard, R.M. (1993). PROCONN: Moment-Rotation curves for Partially Restrained Connections. *RMR Design Group, Inc.*

## 7. ACKNOWLEDGEMENTS

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