Ministry of Higher Education
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BEAM COLUMN CONNECTIONS IN SMART STEEL FRAME SUBJECTED TO EFFECT OF DYNAMIC LOADS

A Thesis Submitted to Council of College of Engineering, University of Diyala in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering

By

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بسم الله الرحمن الرحيم

قَالُواْ سُبْحَانَكَ لاَ عِلْمَ لَنَا إِلاَّ مَا عَلَّمْتَنَا

الْعَلِيمُ الْحَكِيمُ إِنَّكَ أَنتَ

صدق الله العظيم

(سورة البقرة / آية ٣٢)

DEDICATION

To:

My parents, my brothers, and my sisters without them none of this would be possible.

ACKNOWLEDGMENT

In the name of Allah, the most Gracious the most Merciful

Thanks to Allah first and foremost…

I would like to express my deepest appreciation and sincere gratitude to Professor Dr. Ali L. Abbas, for the guidance, advice, and cooperation; Thanks for expensive time that he gave throughout the steps of this study. I'm proud to be his student.

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BEAM COLUMN CONNECTION IN SMART STRUCTURE SUBJECTED TO EFFECT OF DYNAMIC LOAD.

By

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ABSTRACT

This study evaluates the seismic performance of steel frame with new type of partially restrained connection using shape memory alloy (SMA). superelastic form of shape memory alloy has large recoverable deformation upon removal the load is used in current study. The suggested connection consists of 16 steel bars and SMA bars (25.4mm) in diameter. 3D Finite element simulation using ABAQUS v.2017 software is developed, and their result was compared with an experimental test to validate the solution. This study aims to explore the effect of integrated SMA bars within frame on recentering ability, storey drift, residual storey drift, residual displacement, Energy dissipation, peak floor acceleration, stress and residual stress in the system.

Eleven steel frame (one storey frame with two damage factor (10, 100) and two storey frame with three different combination of steel bars and SMA bars) (100% steel bars, 50% steel bars and 50% SMA bars, 100% SMA bars for each case), frame equipped with 100% steel bars was chosen as reference model.

At the beginning of analysis, models were simulated under effect of free vibration and shows the six Eigen modes and frequency for one storey and two storey.

In case of one storey with damage factor =10 the addition SMA bars with percentage is (50%, 100%) instead of steel bars which lead to decease the residual roof displacement by (32.93%, 72%) respectively as compared with reference model , which also lead to decrease the stresses and residual stresses in frames.

While increasing earthquake intensity for one storey cases for frame equipped with 50% SMA bars and 50% steel bars they enhance the recentering ability with ratio (83.5%) as compared with reference model, thus lead to reduction in residual displacement and residual storey drift by (47.08%) as compared with reference model.

While in case of two storey frame , the results of numerical study shows that the adding SMA bars in frame instead of steel bars with ratio of (100%, 50%) improved strong recentering ability with the ratio (136%-98%) respectively, as compared with reference model, in addition the reduction in residual roof displacement is (158.72%, 82.7%) in case of frame equipped with 100% SMA bars and frame equipped 50% SMA bars and 50% steel bars respectively, as compared with reference model. Also adding SMA bars instead of steel bars in frame lead to good contributes towards reduces the stress and residual stress.

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NOTATIONS

$f(t)$	External Dynamic Forces as A Functions of the Time
t	Time (second)
Δt	Increment of time (second)
ω_n	Natural Frequency (HZ)
ω_d	Damped natural frequency (HZ)
E	Young's Modulus (Mpa)
υ	Poisson's Ratio
ε_{nor}	Normal Strain (mm/mm)
ε_{in}	Engineering strain (mm/mm)
σ_{nor}	Normal Stress (Mpa)
σ_{true}	True stress (Mpa)
τ	Shear Stress (Mpa)
μ	Coefficient of friction
ρ	Mass Density (kg/mm^3)
U	Relative Displacement of the System (mm/mm)
G	Gravitational Acceleration (mm/s^2)
K	Stiffness Matrix of Entire System (N/mm)
ζ	Damping ratio
$\ddot{x}_g$	Earthquake ground acceleration (mm/s^2)
$x(t)$	Relative displacement of structure (mm)
$\dot{x}(t)$	Velocity of structure (mm/s)
c_c	damping of control system/device
m_c	mass of control system/device (kg)

k_c stiffness of control system/device (N/mm)

$f_c(t)$ Control force (N)

i_m inertia force. (kg. mm^2)

D_m damping force (Ns/mm)

R_m amplitude of restoring force (mm)

$\sigma_{\dot{x}}$ velocity response

σ_R restoring force (N)

σ_D damping force(N)

ML local magnitude

A is maximum amplitude of the displacement of the terrain (mm)

A* correction.

Ds drift of storey (mm)

$u$up horizontal displacement at the top of a storey (mm)

$u$up horizontal displacement at the bottom of a storey. (mm)

Hs height of the storey (mm)

B^T Strain Displacement Matrix

B Function of The Dis

δX Displacement Increment

Ms Mass Matrix Having Non-Zero Masses for the Structural Degrees of Freedom

ABBREVIATIONS

Symbol	Definition
FEM	finite element method
PGA	peak ground acceleration
SDOF	single degree of freedom
DOF	degree of freedom
AISC	American institute of steel construction
FR	fully restrained.
FS	full strength
PR	partial restrained.
SMRF	special moment resisting frames
SMAs	shape memory alloys.
Ni-Ti	nickel titanium.
Nitinol	nickel titanium naval ordnance laboratory.
CuAlBe	copper based alloys.
FE	finite element.
CFT	concrete filled tube
SE	superelastic effect.
SME	shape memory effect.
CHS	circular hollow section.

CHAPTER ONE

INTRODUCTION

1.1 INTRODUCTION

Connections are categorized by three main parameters stiffness, strength, and ductility. For Stiffness connections are categorized as fully restrained (FR),partially restrained (PR) or simple pinned connection, While the strength connections are categorized as either full strength (FS) or partial strength (PS) depending on whether or not they can transmit the full plastic moment (MP) of beam. The ductility connections are categorized as brittle or ductile connection based on their ability to achieve a certain plastic rotation demand. As shown in figure (1.1) (Hu, 2008)

The rotational demand at the connection varies according to whether they are utilized in ordinary, intermediate, or special moment frame .For example, an aftermath of the earthquake in Northridge, the capacity to undergo an elastic rotation of (0.01 rad.) and plastic rotation of (0.03rad.) is accepted under cyclic loading as the rotational limit between brittle and ductile connections for special moment resisting frames(SMRF). This limit agrees up to a 20% decrease from the peak bending resistance at a rotational limit. (Hu, 2008)

The conventional design strategies for seismic resistant connections normally induce unrecoverable post-earthquake deformations either in the beams (for full strength connections) or in the connections (for partial strength connections), both of which are costly and difficult to repair. An early attempt to address this issue was to incorporate posttensioned high-strength bars within the connections to provide a self-centring mechanism. In parallel with these studies, recent interest has

been directed to material-based recentring connections. Among these innovative investigations, practical application of nickel – titanium (NiTi) shape memory alloys (SMAs) has emerged recently as an encouraging solution in the area of seismic engineering. In particular, the ability of SMAs to undergo reversible deformations of up to 8% strain (either via heating for martensitic SMA or via unloading for austenitic SMA) and to dissipate a moderate amount of energy during cyclic loading makes them promising candidates to be used as structural components against earthquake loading. In addition, The excellent corrosion resisting performance of SMA (equivalent to stainless steel) may overcome the ageing, durability. (Fang et al. 2013)

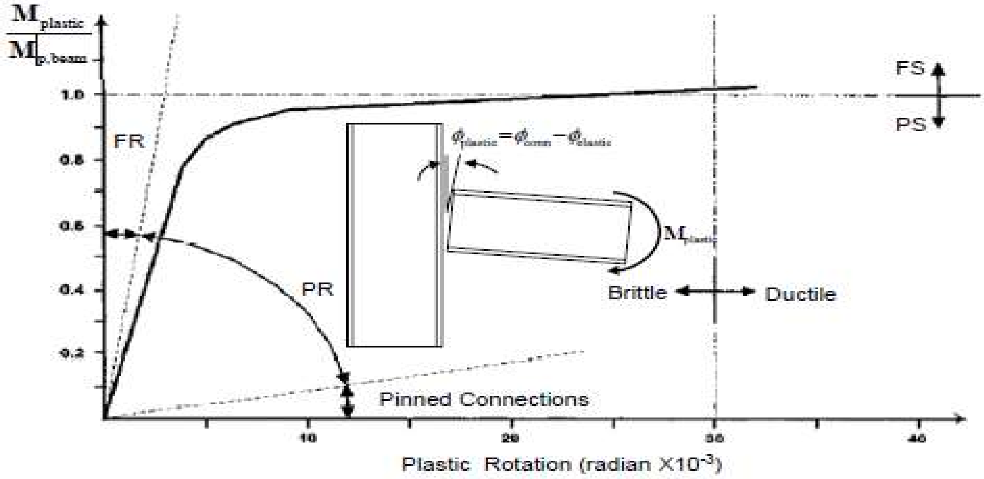


Figure (1.1) Typical moment-rotation curve. (Hu, 2008)

1.2 SMART STRUCTURE

Recent researches explore man-made and natural materials with unusual characteristics called smart materials and system that can spontaneously adjust themselves to change in environment called adaptive system, This lead to innovations of smart structure concept when smart materials are integrated within structure the structure becomes smart (Cheng, F. Y., et al. 2008), Smart structure for civil engineering is defined as system that can spontaneously adjust structural properties in response to unanticipated severe loading and external disturbances. The idea is that the structures can contribute towards response which result in improving serviceability, structural safety, and extension life of structure. (Hu, 2008) smart structure system is characterized by

1-Having sensation ability to any variation in external action

2-Monitoring any problems at critical location.

3-Measuring and processing data.

4-Taking suitable actions in order to improve the system performance with preserving safety of structure, integrity, serviceability. (Anwar, Aung and Najam, 2017) as shown in figure (1.2).

Figure (1.2) The important players in smart structure technology. (Anwar, Aung and Najam, 2017)

1.3 TYPES OF SMART MATERIALS

They are utilized to develop dampers, sensors, and structural components with embedded smart material for actuation and sensing. Structural members with embedded smart materials, sensors, and dampers are applied in the structures of civil engineering such as these structures which have the ability to respond automatically to the seismic activity in order to minimize undesired effects (Cheng, F. Y., et al. 2008)

Types of smart materials

1-electrorheoloicalogical (ER)

2-magnetorheologicol (MR) materials

3-piezolectric (PZT) layers

4-shape memory alloys (SMAs), will study in this thesis.

1.3.1 Shape Memory Alloys (SMAs)

Nickel-Titanium alloys (NiTi) are class of an extraordinary of metal that displays several unique properties such as the ability to recover large deformation with little permanent of the residual strain, through up heating (shape memory effect) or unloading (superelasticity effect). Superelastic Nitinol (nickel titanium naval ordnance laboratory) is a type of SMA with unique ability to sustain large strain as high as (6-8%) ,high strength, large fatigue resistance, and high damping. among these properties, the superelasticity makes them desirable for passive vibration control systems. During deformation, SMA will undergoes to phase transformation (solid to solid) between its stable two phases namely austensite and martensite. typical martensite is stable at high stress, whereas austenite is stable at low stress levels, when it loaded the nitinol transform from austenite to martensite,

upon unloading the martensite transform back to its original parent or austenite phase.(DesRoches et al., 2004). The recovery shape shown in figure (1.3).

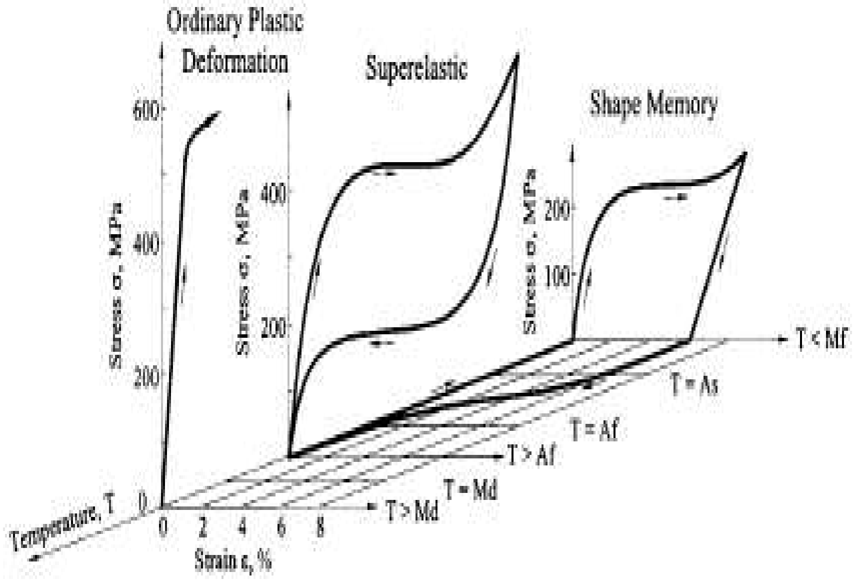


Figure (1.3) Stress-strain-temperature relationships in SMA.(DesRoches, McCormick and Delemont, 2004)

Using superelastic nitinol (Nickel-Titanium Naval Ordnance Laboratory) bars in steel beam column connection as moment transfer elements creates smart structure that spontaneously adjusts to seismic action (Hu, 2008), as shown in figure (1.4). This kind of connection does not only hold all the benefits of bolted PR connections summarized above, but also provides the recentering ability due to the little permanence of residual strain in the SMA tendons. Table (1-1) summarizes properties of SMA Nitinol compared to a typical structural steel.

Table(1-1): Properties of SMA Nitinol compared to a typical structural steel (Penar, 2005)

	Nitinol **Austenite phase**	**martensite phase**	**structural steel**
Physical properties			
Melting point	1240	13190ºC	1500ºC
Density	6.45 g/cm^3		7.849g/cm^3
Thermal conductivity	0.28 W/cmºC	0.14 W/cmºC	0.65 W/cmºC
Coeff. Of thermal expansion	11.3*10^-6/ºC	6.6*10^-6/ºC	11.7*10^-6/ºC
Mechainal properties			
Recoverable elongation	Up to 8%		0.2%
Modulus of elasticity	30-83Gpa	21-41Gpa	200Gpa
Yeild strength	195-690Mpa	70-140Mpa	248-517Mpa
Ultimate tensile strenght	895-1900Mpa		448-827Mpa
Elongation at failure	5-50% (typically 25%)		20%
Poisson ratio	0.33		0.27-0.30
Hot workability	Quite good		Good
Cold workability	Diffecult due to rapid work harding		Good
Machinability	Diffecult, abrasive techniques perferred		Good
Hardness	30-60 Rc		Varies
Weldability	Quite good		Very good
Electrical properties			
Resistivity	100 μΩ .cm	80 μΩ .cm	13-125 μΩ .cm
Chemical propertis			
Corrosion performance	Excellent (similar to stainless steel)		Fair

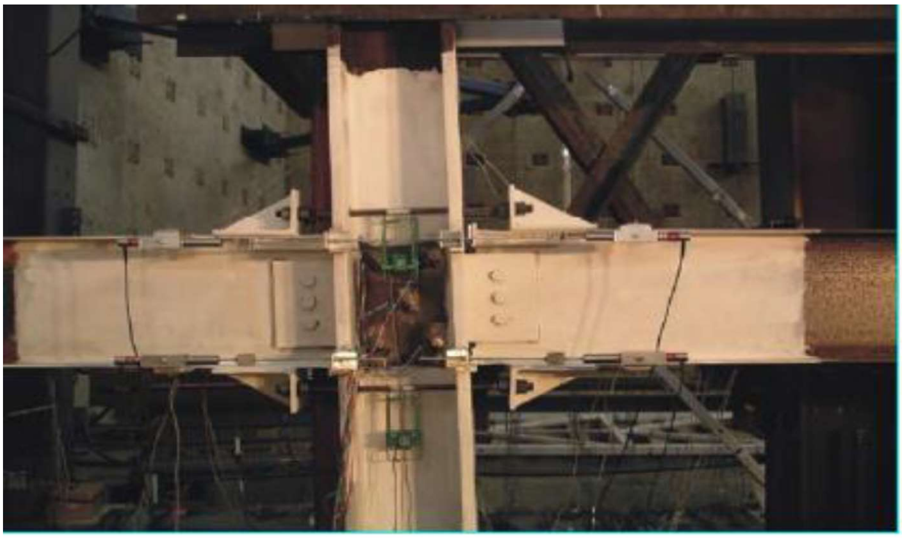


Figure (1.4) Superelastic Nitinol tendons connection.(Penar, 2005)

1.4 EARTHQUAKE INTRODUCTION

1.4.1 General Aspects

Earthquakes "are geological phenomenon produced by the sudden release of energy in seismic sources، located at different depths tens of kilometers or hundreds of kilometers, and generate seismic waves". Earthquakes are obvious by means of the seismic wave at the ground surface, with a period that can be displayed in terms of seconds (tens or hundreds of seconds). (Inculet, 2016) The scheme of an earthquake is shown in figure (1.5)

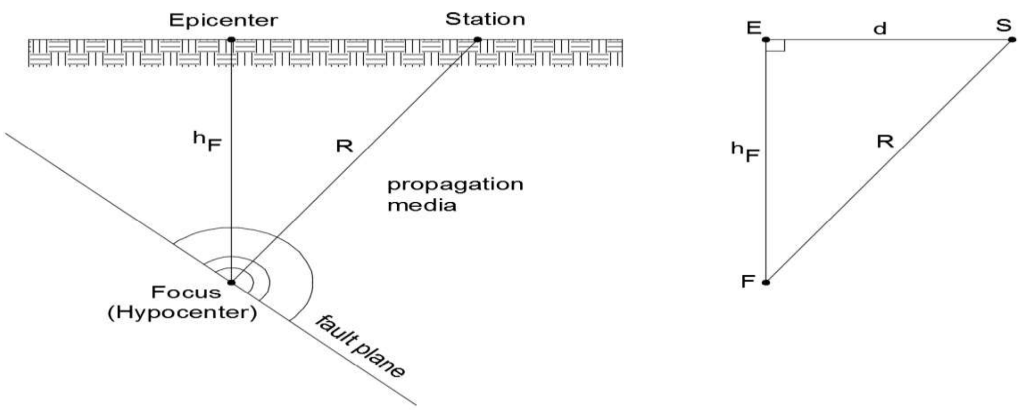


Figure (1.5) Scheme of an earthquake (Inculet, 2016)

(F): Focus (hypocenter), theoretical point in which the process of rupture and release of seismic energy is initialized

(E): Epicenter, point on ground surface that is connected with the focus with a vertical line

(S): Seismic station, where the accelerograms are recorded

hF: Focal depth

(R) :Hypocentral distance

The seismic energy that is released in the source of seismic and it is transferred throughout the media of propagation by means of propagation waves. The source of seismic depends on the depth of the hypocenter (focal depth), (Inculet, 2016)**.** earthquakes are classified in to:

- surface earthquakes:: hF 60 - 70 km
- intermediate earthquakes:: 70 km < hF < 250 - 300 km
- deep earthquakes:: 300 km < hF < 700 -800 km.

1.4.2 Seismic Waves

The seismic waves are the waves that travel through a propagation media structure as result of an earthquake. They propagate in all directions and there are of two types:

1- Body waves:

That are propagated inside the earth's body. Its velocity depends on the materials that are cross, and on the distance to a hypocenter. The body waves also consist of two types:

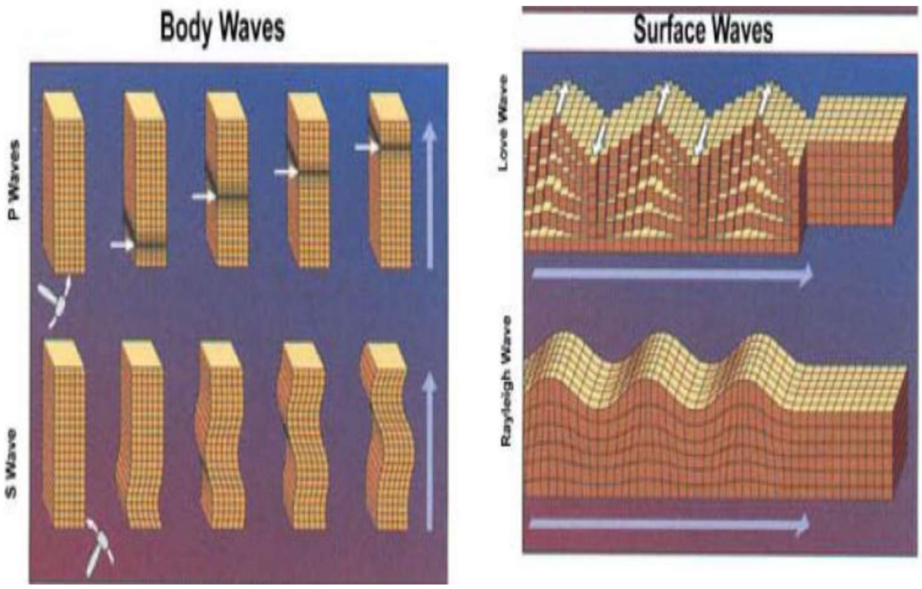
- P waves, also called primary waves, compression waves or longitudinal waves, are propagated roughly in a straight line manner. They are the fastest type of seismic waves, the first ones to be recorded by the seismopraphs.

- S waves, also called secondary waves, shear waves or transversal waves, propagated perpendicular to the direction of the P waves. As shown in figure (1-8) a, (Inculet, 2016)

2- Surface waves:

These the waves are directed by the surface of the earth. They are of less velocity than the body waves but their amplitude is commonly higher. There are two types of surface waves:

- Love waves: are the fastest than surface waves. It is horizontal shear waves and can be observed as S waves without horizontal component.
- Rayleigh waves: are seismic surface waves which are likened to the waves at the surface of a lake, with both vertical and horizontal components. The propagation of the seismic waves is showed in Figure (1.8) b.



(a) (b)

Figure (1.8) Propagation of the seismic waves, (a) body waves, (b) surface waves, (Inculet, 2016)

1.4.3 Seismic Magnitude

The seismic magnitude is the factor determination according to the readings recordings at the ground level, used for featuring the severity of a seismic event. This factor has an energetic signification.

- **Richter scale.**

is developed by Charles Francis Richter in 1930,The magnitude is defined equally logarithm on base 10 of maximum amplitude of a displacement (measured in μm) measured by a standard seismograph at a distance of (100)km from epicenter of earthquake on a hard terrain. (Inculet, 2016)

$$\mathrm{ML} = \log A/A^{*}$$

Where

ML is local magnitude.

A is maximum amplitude of the displacement of the terrain,

A* is correction.

1.4.4 Seismic Intensity

The seismic intensity (not to be confused with magnitude), scales with separate values which depend on the effects on earth surface from the earthquake. The intensity scales are the Mercalli modified scale (MM56), the European Macroseismic Scale (EMS-98) and the Medvedev Sponheuer Karnik scale (MSK).(Inculet, 2016), table (1.2) Modified Mercalli intensity (MMI) scale. (Inculet, 2016)

Table (1.2) Modified Mercalli intensity (MMI) scale (Datta,2010)

Instrument intensity	**Evaluation**	**Description**	**Magnitude (Richter scale)**
I	Insignificant	Only detected by instrument	1.0-1.9
II	Very light	Only felt by sensitive people oscillation objects	2.0-2.9
III	Light	Small vibratory motion	3.0-3.9
IV	Moderate	Felt inside building, noise produced by moving objects	4.0-4.9
V	Slightly strong	Felt by most people, some panic, minor damage	
VI	Strong	Damage to non-seismic resistant structures	5.0-5.9
VII	Very strong	People running some damage in seismic resistant structures and serious damage to un-reinforced masonry structures	
VIII	Destructive	Serious damage in structures in general	
IX	Ruinous	Serious damage to well-built structure, almost total destruction of non-seismic resistant structures	6.0-6.9
X	Disastrous	Only seismic resistant structure remain standing	7.0-7.9
XI	Disastrous in extreme	General panic, almost total destruction, the general cracks and opens.	
XII	Catastrophic	Total destruction.	8.0-8.9

1.5 OBJECTIVES OF STUDY

This study present numerical analysis by the FEM (ABAQUS version 2017) to simulate smart steel frames using steel and superelastic SMA tendons as tension fastener in smart SMA PR beam column connection under dynamic loading, The overall objectives are

1- improve the seismic performance of smart steel frame with SMA bars that give superior performance in terms of ductility, seismic behavior, energy dissipation.

2- This study is intended to take benefit of the unique characteristics of shape memory alloys to provide a moment resisting connection with recentering capabilities.

1.6 OUTLINE OF THESIS

This thesis is divided into five chapters a brief description of each chapter contents is presented below:

1.Chapter One : provides a brief introduction about the PR connection , SMA materials and earthquake introduction.

2.Chapter Two: provides a brief literature review on subject related to SMA PR connection and frames with PR SMA bolts subjected earthquake loading.

3.Chapter Three: deals with finite element method program (ABAQUS version 2017), to simulate the behavior of the PR connection frame under earthquake action.

4.Chapter Four: includes the case study represented by finite element method for frame structure under the effect of dynamic load and a verification problem of frame structure is reanalyzed.

5.Chapter Five: is the conclusions drawn from study carried out together with recommendations for future studies.