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Behavior of Smart Reinforced Concrete Beam Column Joints Under Monotonic and Repeated Loading

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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CERTIFICATION

I certify that the thesis entitled **" Behavior of Smart Reinforced Concrete Beam Column Joint Under Repeated Loading"** is prepared by **"Maha Qassim Hameed"** under my supervision at the Department of Civil Engineering-College of Engineering- Diyala University in a partial fulfillment of the Requirements for the Degree of **Master of Science in Civil Engineering**.

Signature:

Supervisor:

Date: / /2022

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيم

{وَمَا أُوتِيتُمْ مِنْ الْعِلْمِ إِلاَّ قَلِيلاً}

(سورة الإسراء85)

Dedication

To my dear mother and dear father who have always loved and supported me unconditionally.

To my lovely husband who has been a constant source of support and encouragement during the challenges

To my brothers and sisters and friends .

To those who struggle for their freedom.

To those who pursue a meaning for their lives.

To mankind.

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*I would like to thank God for his countless blessings and for facilitating my study, then I'd like to thank (**Prof. Dr.** **Ali Laftah Abbass**). No words can appreciate him and his support to achieve this work.*

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Finally, I want to thank all of my friends who have helped and supported me in my work.

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ABSTRACT

Using the super elastic materials in structures design is becoming apparent in the research feild because of their rare ability in sensing the around effect and reacting against the mechanical and thermal react. The major intent in this research is designing smart reinforced beam column joints by Shape Memory Alloy (SMA) bars.

The suggested systems use the Pseudo Elastic (PE) react of the SMA as reinforcement after being subjected to monotonic and repeated load. The behaviors of systems were explored experimentally and validated by using finite element simulation. At first stage, the design of reinforced steel dual interior beam column joint was managed and checked by using experimental test on large-scaled joints.

The design of the reinforced joints by utilizing SMA bars (50% of the flexural reinforcement) was conducted then , the experimental test of the joint specimens was carried out to inspect the transfer of the forces. Also, the mechanical steel couplers used to make strong anchorage for the SMA bars in the connection area. The experimental tests of the large-scaled SMA joints showed their better performance comparing to the ordinary one in the term of absorbed energy. In order to estimate load-displacement relationships of these specimens in third stage of this study , analytical models were developed.

a parametric comparision study of specimens reinforced by SMA was carried out. It contained a variance in percentage of the SMA in flexural reinforcement (25%, 50%, 75%) of the total flexural reinforcement, and using

various values of the compressive strength had a clear effect on the ultimate load and the ultimate displacement of the specimens .

the results shows increasing the the ductility of SMA specimens about (52%) under monotonic loading and decreasing about (21.5%) under repeated loading, also there is decreasing in ultimate load by using SMA bars about (12.8%) in case of monotonic loading and (10.2%) in case of repeated loading. And the absorbed energy increased by using SMA about (34.26%) from the joint reinforced by steel bar and deflection increased about (63.5%) under monotonic load and (46.25%) under repeated loading from the joint reinforced by steel bars, For the numerical analysis the results shows that The ultimate load decreased by using SMA bars in (25%, 50%, 75%) of total flexural reinforcement about (5, 16, 47 %) respectively, in case of monotonic loading and 20, 10, 9 %) respectively in case of repeated loading, the deflection is increasing by using SMA in (25%, 50%, 75%) percentage of total flexural reinforcement about (3, 8, 27%) respectively, in case of monotonic loading and (17, 31, 59 %) respectively in case of repeated loading. The ultimate load of 42 MPa specimens decreased by using SMA bars 50% percent of total flexural reinforcement in case of using (28)MPa compressive strength about (12%) but it increased in case of using 65 MPa in about 19%, in case of monotonic loading and it decrease about (5%) for 28 MPa and it increased about (5%) for 65 MPa respectively in case of repeated load.

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List of Symbols, Abbreviations and Nomenclature

Symbol	***Definition***
Af	Austenite finish temperature
As	Austenite start temperature
db	bar diameter
Dc	concrete compressive damage
Dt	concrete tensile damage
Ec	concrete modulus of elasticity
fc	concrete compressive stress
f' c	concrete compressive strength
fs	stress in the reinforcement
ft	concrete tensile stress
fu	stress at ultimate
fy	yield stress
Pcr	cracking load
FEM	Finite Element Method
M	applied moment
Mf	Martensite finish temperature
N	Nitrogen
Ni	Nickel
O	Oxygen
P	applied load
PE	Psuedoelasticity Effect
RC	Reinforced Concrete
SMA	Shape Memory Alloy
SME	Shape Memory Effect
T	temperature
Ti	Titanium
w/c	Water to Cement Ratio
$\mu\Delta$	displacement ductility
σ	stress
σu	stress at ultimate load
ψ	Curvature ductility
σds	detwinning start stress

ρ	Ratio of Tension Reinforcement Equal to As /(b_wd)
2D	Two-Dimensions
3D	Three-Dimensions

CHAPTER ONE
INTRODUCTION

1.1 General

The earthquake amplitude designing technique is based first on the confirmation of failure in ductile state by dissipating energy in certain places in structure . The meant places are coded as plastic hinges (i.e. center of rotation) and are articulated to confirm bend failure and stop unwanted failure in shear state (see figure 1-1). To prevent collapse by forming a so- called "beam mechanism", the places and advancement of the plastic hinges are designed. This technique refers to the formula Plastic hinges in frame work are in the face of the columns in the girders followed by plastic hinges crafting in columns in the primary rung (Paulay and Priestley, 1992).

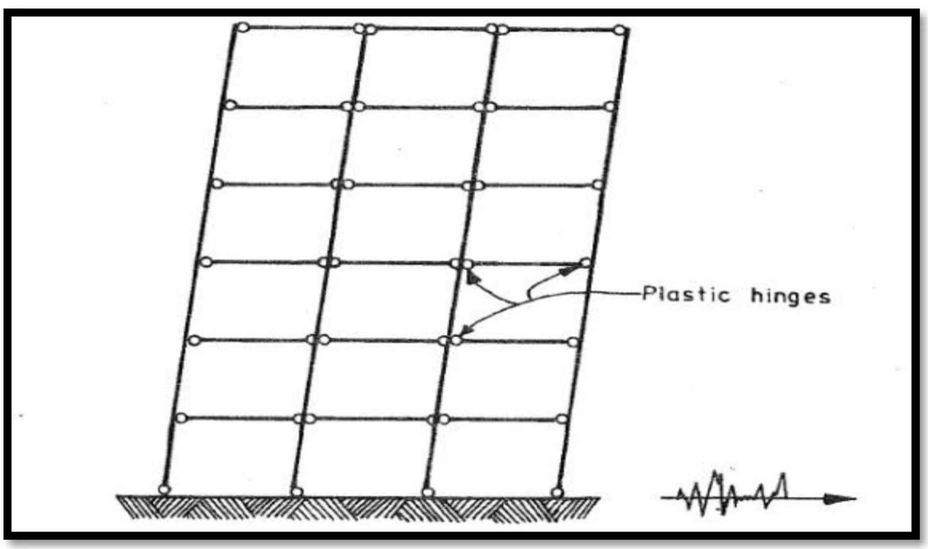

Figure 1-1: Beam sideway mechanism for a frame under seismic loading (Charles Walter Beckingsale, August, 1980)

So the dissippation of energy imposed on the structure through the bending deformation plastic hinges will be caused .The development of “smart” structural components : Beam, shaft and beam joints concider the one of the master research acheivments to the seismic design field of structures.

Smart parts have the energy dissipation capability caused by devices of energy dissipation, back to the initial equilibrium point upon discharge. As example Using superelastic nitinol (Nickel-Titanium) bars in steel beam column joints as transfering moment parts creates smart structure that adjusts to seismic action at onces (Hu, 2008), as shown in figure (1-2).

Figure (1-2) Superelastic Nitinol tendons connection.(Penar, 2005)

The practical application of nickel-titanium (NiTi) shape memory alloy has lateraly emerged as an hopeful solution in the field of seismic engineering. particularly, the capability of Shape Memory Alloys (SMA) to undergo inverse deformations of up to 8% strain (either by heating of martensitic SMA or by unloading austenitic SMA) and to dissipate a medium quantity of energy during repeated loading makes them a promising candidate for use as structural parts against seismic loading .Addition, the excellent corrosion resistance performance of SMA (stainless steel equivalent) may beat aging and toughness. (Fang et al. 2013)

The Shape Memory Alloy is An alloy have amazing and unique properties which is it undergo large deformation and dissipate energy while maintaining a superelastic response. The premium properties of SMA makes it an excellent choice for the the seismic design of structures. The use of SMA for this research in monolithic concrete beam-column connections is optimized during the development of plastic hinges in concrete beam-column joints .

1.2 Smart Structures

Recent researches explore manufacturing and natural materials with uncommon characteristics called smart materials and system that can automatically adjust themselves to change in environment called adaptive system, This leads to inventions for the idea of smart structure When smart materials are incorporated within the structure the structure will be smart(Cheng, F. Y., et al. 2008).

For civil engineering smart structure was define as system that can automatically adjust structural properties in response to unanticipated acute loading and exterior disturbances. The idea explains the structures can contribute to response which produces in development serviceability, structural safety, and increasing life of structure. (Hu, 2008) smart structure system is characterized by

1. Having sensation capability to any change in external action
2. controlling any problems at critical location .
3. Measuring and processing data .
4. Taking appropriate steps in order to develop the system performance with keep safety of structure, integrity, serviceability. (Anwar, Aung and Najam, 2017) as shown in Fgure (1-3).

Figure (1-3) The Important Players in Smart Structure Technology (Anwar, Aung and Najam, 2017).

1.3 The Aim of Study

The first preference in earthquake design is to reduce losses in lives, which need perhaps lost of the utilization of the structure when exposed to earthquake. But, revolutionist design mechanisms related with the utilization of new texture materials can be utilized in order to accomplish a smart way of behaving with impressive produce of dissipation of energy in monolithic Reinforced Concrete (RC) structures.

The SMA is a rare alloy had the capability to bear huge deformations and back to the original shape when stress removed (psuedoelasticity) or heating (shape memory effect) (Kumar and Lagoudas, 2007) The cyclic response of SMA is shown in Figure (1-4).

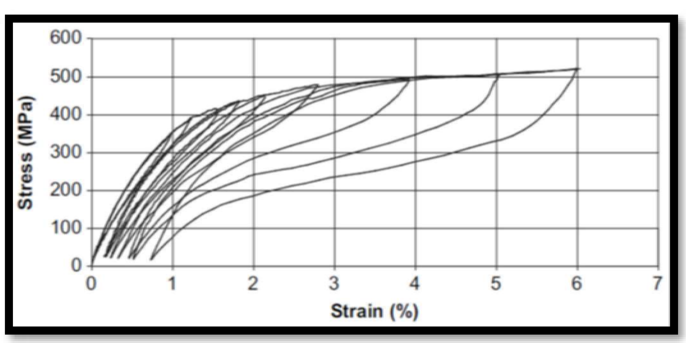

Figure (1-4)] Relationship of Stress-Strain for SMA (Youssef et al., 2008).

The exceptional charastaristic of SMA in restoration significant inelastic deformation after loading had diminished makes it extremely worth in seismic design. Thus, in the event that this alloy is utilized in the spot of plastic hinges with appropriate limitation design , the construction will disperse the requist energy and return to its elder shape when unloaded.

The significant enumerating rules that were considered in this research is continuance of the steel reinforcement . The duration of the steel reinforcement will disallow the total collapse up to arriving at the failure state . In the proposed system , the failure is characterized as the crack of the Pseudoelastic PE SMA rebars while the complete collapse is indicate to the breakage of the beam member at the area of the plastic hinge .

1.4 Significance of Research

Despite the fact that moment resisting RC structures designed by the limitation of capacity design methods are secured, or at least, with little likelihood of collapse at seismicdesign ground-movement intensities , they might support broad damage with fix expenses of around 33% of the structure substitution esteem (Ramirez et al., 2012). The utilization of SMA self-centring beam column connection proposed in this study won't just keep up with the usefulness of the construction subsequent to being exposed to quake movement, yet it will likewise contribute in decreasing the maintenance expenses of the primary and non-structural component of RC resisting frames.

1.5 Objectives

The general target of study is to configurate smart concrete Beam Column Joints reinforced by smart materials. To accomplish this goal, the project is partitioned into sub-targets as follows:

1. Review the future advancements of beam column connection systems and the factors that influence the reaction of SMA material.

2. Design and checked out the convenient steel system built up utilizing regular steel.
3. Identify the monotonic and cyclic properties of SMA material for the utilization in seismic design applications.
4. Design and checked out the the reaction of joint specimens reinforced utilizing SMA bars and compare it to joints built up utilizing steel reinforcement.
5. Develop a numerical model that can show the reaction of the smart joints built up utilizing steel and SMA bars.
6. Develop and validate 3D Finite Element (FE) models of the tested connection utilizing the ABAQUS to be utilized for leading a parametric study in future research.

1.6 The Scope of Work

The project is partitioned into three fundamental stages that are worked toward accomplishing the general target of the research. The principal stage incorporates the design and validation of the BCJs utilizing steel reinforcement. Models are utilized to decide the forces inside the system and to design the flexural reinforcement as needs be.

The second phase is the experimental testing of four large-scale connections two of them reinforced conveniently and the other reinforced by substituting 50% of flexural reinforcement with nitinol smart bar, monotonic and repeated loading was set to one convenient connection and one SMA connection in order to determine its approval for seismic applications.

From that point onward, the reactions of this four joint examples built up utilizing convenint steel and SMA bars are examined experimentally to determine the effect of the flexural behavior .Besides, the anchors and the couplers are made to reduce the slippage and achieve high strain and sress level. The third part of this research is the improvement of numerical and FE models built up utilizing steel and SMA bars.

1.7Content of Thesis

The thesis comprises of six parts. The requirement for the improvement of smart BCJs is recently portrayed in this chapter . alongside the objectives and the scope of work of the current study . Regarding the principle parts of the project talked about in Section 1.5, the substance of the next parts are:

Chapter One: Introduction.

Chapter Two: It incorporates the important information , the various systems utilized design of BCJs , outline of the pseudo elastic reaction of SMA, and a literature review about the uses of SMA material inconcrete structure design.

Chapter Three: Experimental work which is containing designing and testing specimens.

Chapter Four: The results of the the pervious chapter

Chapter Five: The validation of the experimental work and development of FE models in this part

Chapter Six: Conclusion for the results that gathered and recommendation for future works