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HYSTERSIS BEHAVIOR OF R/C MEMBERS WITH PLAIN BARS

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SUMMARY

The use of plain bars in R/C structures is prohibited in newly developed structural codes. Anyhow, many R/C buildings which plain bars were used as their reinforcement are currently existed in Iran. Iranian government approved a special lumped budget to improve the vulnerability of existing buildings. For that reason a guideline was published for assessment of seismic strength of buildings based on performance based engineering concepts. In order to accurately evaluate the performance of a structure during earthquake a nonlinear earthquake response approach is usually performed. There is a lack in literature to find a proper member hystersis model for nonlinear earthquake response analysis of R/C buildings with plain bars. The objective of this research is to study hystersis behavior of R/C members with plain bars. Two identical R/C structural members one with plain bars and another with deformed bars were designed and constructed in almost same conditions. The members were subjected to cyclic load to obtain and compare their hystersis diagrams. It was observed that pinching behavior was increased in hystersis diagram of R/C member with plain bars, which result in reducing of energy dissipation. Moreover, the use plain bars in R/C members resulted in loss of strength in these structures. Cracks were much concentrated at member ends with plain bars which can lead to shortening of plastic hinge length. Hystersis model of R/C structural members with plain bars can be obtained by applying proper strength reduction factors and pinching factors to conventional models of R/C members with deformed bars.

INTRODUCTION

Plain bars were used in R/C structures according to old DIN structural code in Iran. ACI structural code has been used in Iran since about 1955. Although, the use of plain bars was approved by ACI structural code till 1963, it was prohibited since then due to bad performance during earthquakes. However, Iranian engineers used to design structures with plain bars till 1980. Due to recently killer earthquakes in Iran, the government pushes for strengthening of existing buildings. In order to strengthening and retrofitting of existing R/C buildings with plain bars, a proper member hystersis model is of essential. Unfortunately there is a lack in such proper member hystersis model that implies the effects of bonding and pinching of plain bars. This can be due to lack in experimental results. It is therefore essential to experimentally study the hystersis behavior of R/C structures with plain bars. In this research, an experimental study was conducted to obtain hysteresis behavior of R/C members with plain bars. The results were also compared with the results of R/C members reinforced with deformed bars. The test procedures, observations and results are explained individually in the following sections.

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THE IMPORTANCE OF STUDY

Many R/C structural buildings used plain bars for reinforcement in Iran. During the past earthquakes, the bad performance of plain bars was one of the most causes of damages to R/C buildings. Figure 3 shows a typical one story one span R/C building which suffered heavy damages during Iran-Qayen (Ardakul) earthquake of may 10, 1997 Alaghebandian [2]. During the mentioned earthquake, one of major reasons of damage was the lack of good detailing practice. Most of the structural damage observed in frame buildings was concentrated at column ends. One common inadequate point was the use of longitudinal round bars in column without any anchorage hook at the end. This caused the bars to slip out at the critical regions, leading to unintended premature failure at the column ends, which resulted in collapsing of the buildings. An example of this fact is illustrated in figure 2. Joint shear failure was observed widely in the damaged buildings. Although the current Iranian Seismic Code BHRC [1] calls for continuing the column hoops into beam-column joints, virtually no joint reinforcement was observed in the buildings (figure 2).

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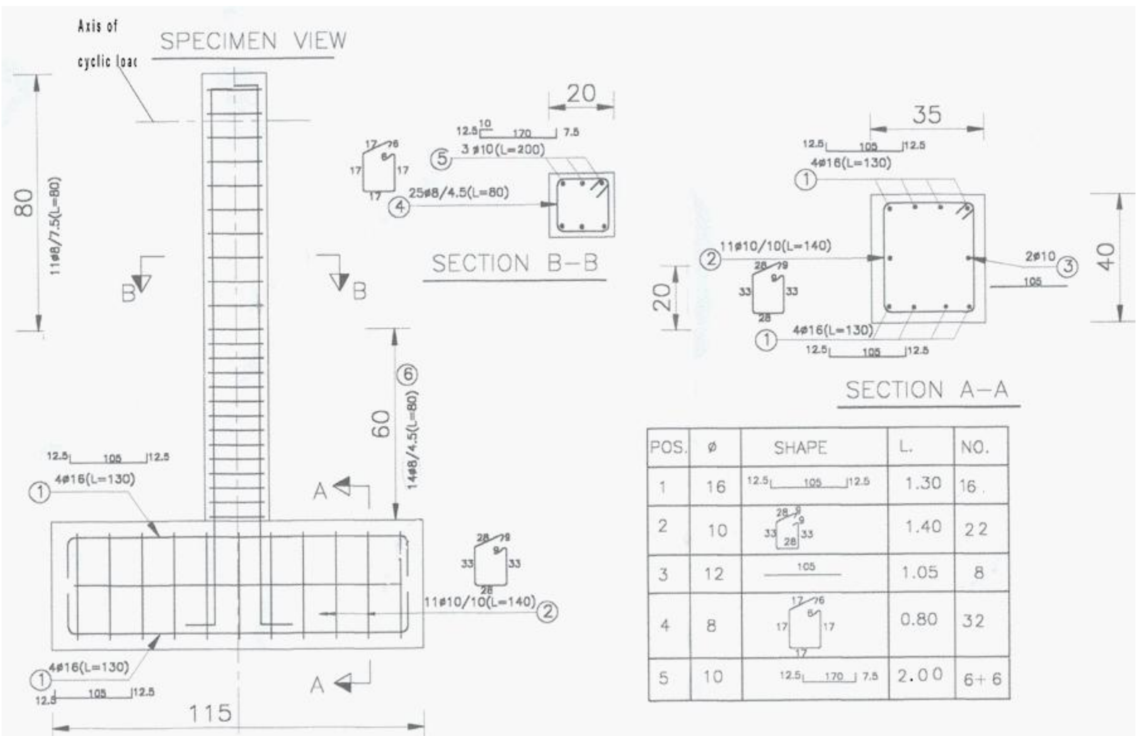
TEST SETUP

Test setup was shown in figure 3. A cantilever member was used which can simulate the seismic behavior of a beam or column with moment contra-flexural point at mid-span during earthquake motion. A 100KN servo hydraulic jack, manufactured by Instron Company, was used to apply cyclic concentrated loads history at a point with a distance of 126cm from top of the stub level. The loading system was controlled by servo hydraulic dynamic actuator systems at the structural laboratory of Tehran University. Data acquisition systems consisted of a static data logger, transducers, and strain gauges, which were obtained from Tokyo Sokki Company.

Figure 3. Setup of the proto-type member test

TEST SPECIMENS

Two half scaled R/C members were designed to meet setup capacity of the laboratory. The member was prototype of a big Hospital in Tehran, which is target for a strengthening project. Lateral steels ratio was adequately large to prevent shear failure. Therefore only flexural behavior was studied. Physical specifications of designed members are shown in figure 4. Two specimens one with plain bars and another with deformed bars were tested. In order to compare the results of the test, the dimensions of specimens, lateral and longitudinal steel ratios, reinforcement detailing, steel types, concrete mixture, and curing conditions were identical for both specimens.
Totally 6 strain gauges were used for each specimens, 3 at each sides. The 3 strain gages were mounted on longitudinal bars at a distance of 2, 10 and 18cm from top of the stub. Strain gages on each side were mounted at the same level. Strain gages were calibrated using simply supported steel plates at the laboratory. The information of calibrated strain gages were monitored and registered at each loading step to find out the mechanical behavior of steel at each step.



POS.	ø	SHAPE	L.	NO.
1	16	12.5 105 12.5	1.30	16
2	10	28 9 33 33 28	1.40	22
3	12	105	1.05	8
4	8	17 6 17 17 17	0.80	32
5	10	12.5 170 7.5	2.00	6+6

Figure 4. Physical specifications of members

MATERIAL PROPERTIES AND SECTION ANALYSIS

The typical steel bars used in construction of reinforced concrete buildings in Iran are indicated in table 1. Usually, the plain round bar (type A1) and deformed bar (type A2) were used in practice, but in this study to compare the results, a specially ordered plain bars (type 2) was used.

Type	Expression	Elasticity Modulus (MPa)	Yield Strength (MPa)	Tensile Strength (MPa)	Fracture Strain
A1	Plain round bar	2.1×10^5	240	380	0.25
A2	Deformed bar	2.1×10^5	300	500	0.19
A3	Deformed bar	2.0×10^5	400	600	0.14

Table 1. Steel bars used in Iran for R/C structures

To determine the material properties, two samples of plain bars and two samples of deformed bars were tested under uniaxial tension test in material laboratory of the University of Tehran. The mechanical properties of steel bars are shown in table 2. As to concrete, four 15*15 cubic specimens were casted and subjected to uniaxial compressive test at the date of member test. The compression strengths of concrete are shown in table 3.

Type of bars	Number of specimen	Fy(Mpa)	Fu(Mpa)	εu	εy
Plain	First	358	488	0.0017	0.19
	Second	342	498	0.0017	0.24
Deformed	First	381	529	0.0018	0.23
	Second	369	522	0.0018	0.18

Table 2. Mechanical properties of reinforcing bars

Type of member	Number of specimen	Compression strength of 15*15 cubic samples
Member with plain bar	First	31.2
	Second	33.3
Member with deformed bar	First	29.9
	Second	34.1

Table 3. Compression strength of concrete

Tensile strength of concrete was assumed to be 10 percent of compressive strength. Initial elasticity Young's modulus of concrete E_c was 2.92×10^4 MPa based on a secant value recommended by AIJ (Architectural Institute of Japan). Moment-curvature diagram for plain bar member and deformed bar member was drawn and compared in figure 5. A parabolic stress-strain relation was assumed for concrete in compression zone at cross section of members, and moment-curvature relation was calculated for a given constant axial force. It was assumed that cylindrical compression strength f'_c is equal to 0.85 of cubic compression strength. It is worth mentioning that average of material properties was used in analysis. It is evident from figure 5 that flexural capacity of the member with deformed bar is about 7% greater than flexural capacity of the member with plain bar. This disparity must be considered when comparing the hysteresis behavior of two specimens.

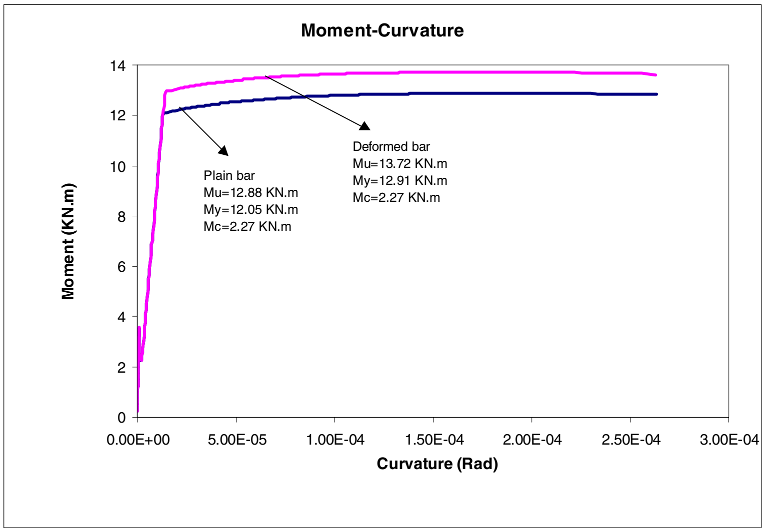


Figure 5. Moment-curvature diagram of members with plain and deformed bars

TEST PROCEDURES

Lateral load was applied to the members based on a displacement control loading steps. Lateral displacements were set to a drift ratio of 0.25, 0.5, 1, 2, 4, 8, 12, and 16 percentages. In each drift ratio, 3 cyclic loading set were applied to simulate earthquake response. It is worth noting that loading steps and drift ratios at each step were set identical for both specimens. The cyclic loading history is shown in figure 6.

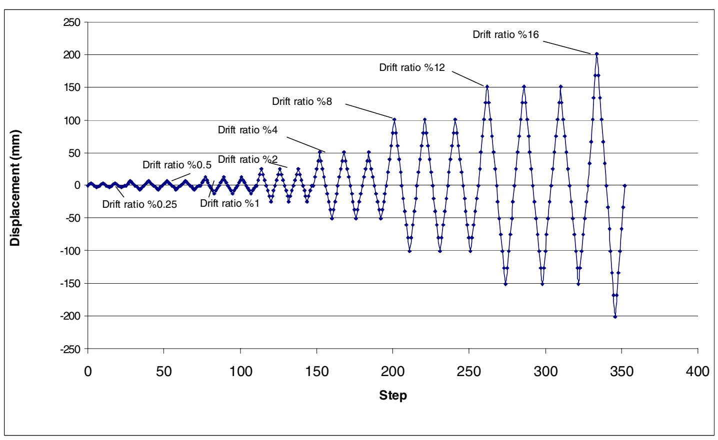


Figure 6. Loading steps and cyclic loading history

Photos of different loading steps at different drift ratio of zero percent, 4%, 8% and 12% for two members are shown in figure 7. Left column pictures related to member with deformed bars and picture of right column related to member with plain bars. The amount of damage and crack development can be monitored easily from these photos. Performing the test, we observed detachment of member from the stub for both specimens but in different loading steps. This phenomenon occurred in the member with plain bars sooner than the member with deformed bar. This can be related to bond problem and slipping out of the plain bars.

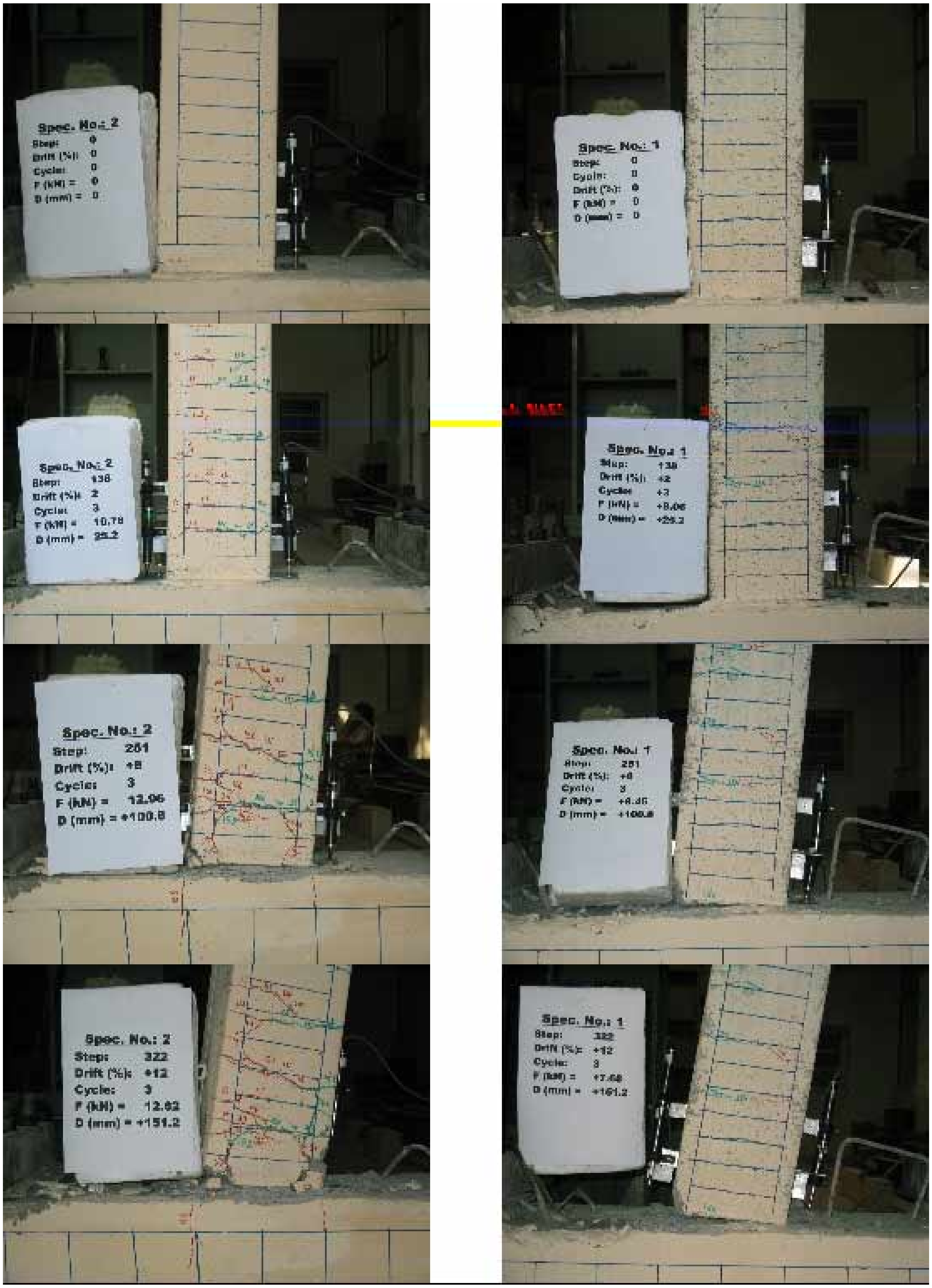


Figure 7. Member with deformed bars (left column) and member with plain bars (right column).

Another different behavior was observing no buckling and steel fracture in member with plain bars. Thought member with deformed bars faced with buckling of longitudinal bars at second load cycle and drift ratio of 12%, and steel fracture of longitudinal bars at first loading cycle and drift ratio of 16%. This is because of loose in bond strength of plain bars and concrete leads to easily slipping out of steel bars. Buckling and fracturing of longitudinal deformed bars are shown in figure 8.

Figure 8. Buckling and rupturing of deformed bars

Cracks in each loading step were drawn on the members. Cracks were marked with loading steps. Therefore a history of crack opening development can be easily studied after the test. It is shown in figure 9 that crack development in the member with plain bar (right side of figure 9) is less than the member with plain bar (left side of figure 9). This can be related to slipping of bars in the member with plain bar. In the member with plain bars main cracks development length was about 0.5D from the stub face (D is the depth of the member), while in members with deformed bars this length was about 1.5D. These distances may be representative of plastic hinge length of the members. It is notable as a matter of fact that number of cracks was diminished when going trough the member from stub face to the loading point. Very few cracks on the stub were observed which indicate a rigid behavior of the stub.

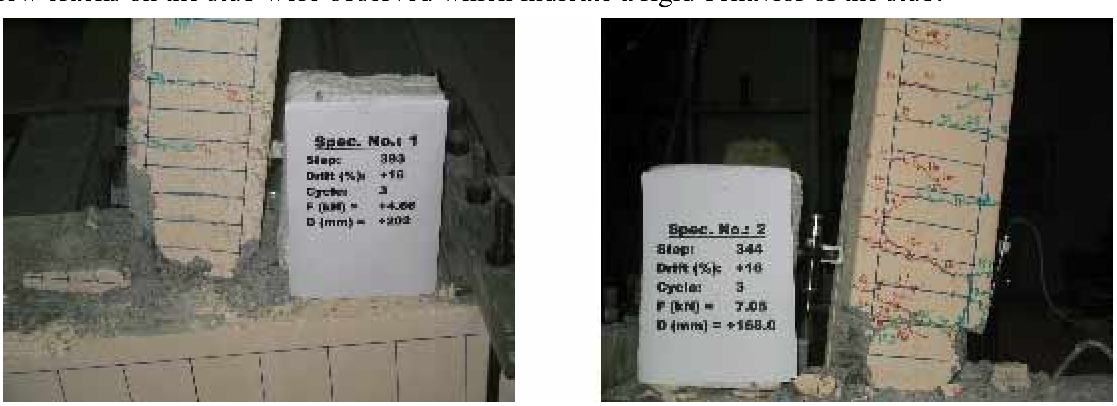


Figure 9. Cracks development in member with plain bars and member with deformed bars

HYSTERSIS DIAGRAMS

Hystersis diagrams of both specimens at drift ratios of 0.25, 0.5, 12, 4, 8, 12, and 16% are shown in figure 11. Hystersis diagrams at all drift ratios are also plotted in figure 10. In all diagrams, notable decay in strength of member with plain bars compare with member with deformed bar is observed at a same lateral displacement. This strength reduction is about 44% at peak strength. Considering the strength lessening from section analysis, it was concluded that a strength reduction factor of about 37% must apply for plain bars effects. Pinching effect in hystersis diagram of member with plain bar is notably increased. The pinching effect which makes diagrams wider at higher relative displacement and makes them narrower at the mid of diagram Otani [3], at the low relative displacement, is obvious in figure10. Horizontal parts in hystersis diagrams indicate the effect of slipping out. Although, this behavior occurred for both types of bars, it is more considerable for plain bars.

Strain gauges revealed that initial yielding of longitudinal steel bars was occurred at a drift ratio of about 0.5 to 1%. And, at a drift ratio of 2% strain gages showed that all bars were yielded. It is notable that loss of force in second and third loading cycle compare with the first cycle obviously occurred which shows the deterioration effect.

Measured displacement at a constant force for the member with plain bar is much greater than measured displacement of the member with deformed bar. As an example, it is evident from figure 10 that with a 9KN lateral force, displacement of the member with plain bar is 50mm but displacement of the member with deformed bar is limited to 13mm.

Considering the above mention points, the hystersis diagram obtained from the member with plain bar must be modeled regarding to reduction in energy dissipation and considerable loss of strength compare with the member with deformed bar. More experimental work is needed to find out a proper strength reduction factor and pinching parameters of members with plain bars.

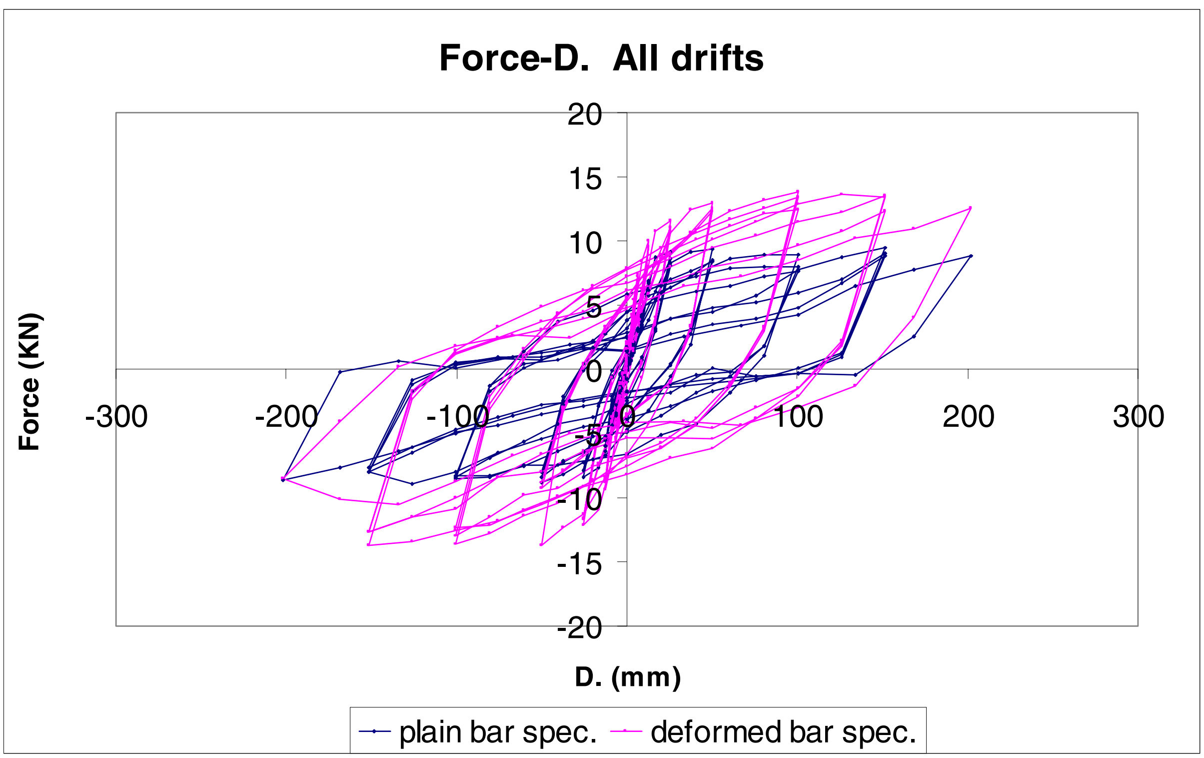


Figure 10.Force-displacement hystersis diagrams of both specimens

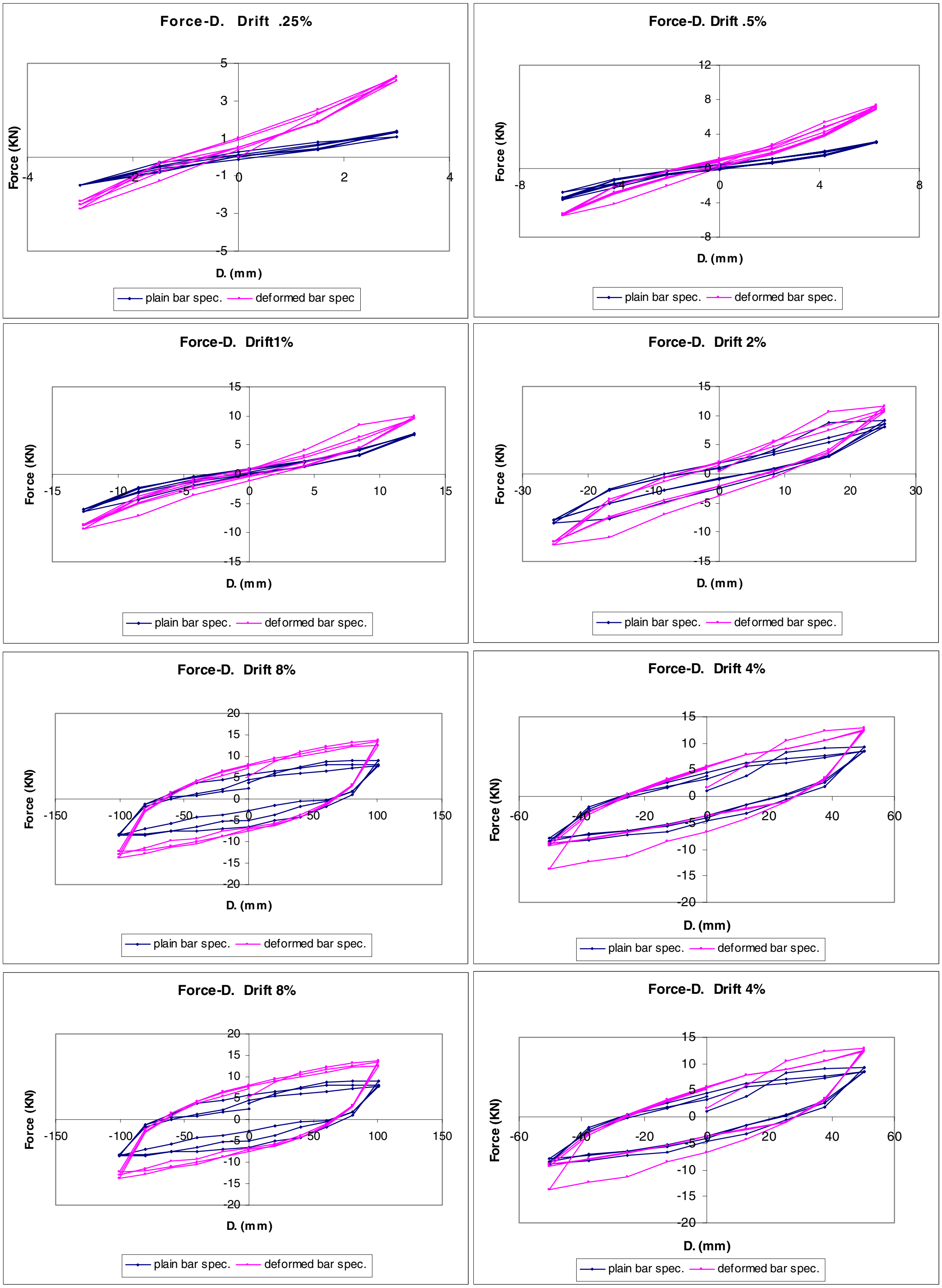


Figure 11. Force-displacement hystersis diagrams in various drift ratios

CONCLUSION

Seismic performance of R/C members with plain bars is poor compare with R/C members with deformed bars. Two main improper behaviors were observed. The first improper behavior was considerable loss in strength of R/C member with plain bar compare with the member with deformed bar. The observed strength reduction was about 37% at peak strength in this experimental study. Another improper behavior was increasing the pinching effect in hystersis diagram of the member with plain bar. This leads to less dissipation of hysteresis energy under same circumstances of member with deformed bar which can result in much destroyed damages during earthquake.

Cracks were much concentrated at starting end of member with plain bars. Consequently plastic hinge length of member with plain bars was about 0.5D (member depth), while it was about 1.5D for members with deformed bar.

According to the results in this research, the hystersis model of R/C members with plain bars can be obtained by applying a strength reduction factor and some pinching factors to conventional models of R/C members with deformed bars. This model can be used in analyzing R/C structures with plain bars in order to evaluate the seismic performance of existed structures for the purpose of retrofitting and/or strengthening. More experimental work is needed to find out a proper strength reduction factor and pinching parameters of members with plain bars.

REFERENCES

1. BHRC, “Iranian Code for Seismic Resistant Design of Buildings,” Building and Housing Research Center (BHRC), Ministry of Housing and Urban Development, Iran, 1988.
2. Alaghebandian, R., “Building Damages During The IRAN-Qayen (Ardakul) Earthquake of May. 10, 1997,” Otani & Shiohara Lab., Dept. of Architecture, The Univ. of Tokyo, Japan, Nov. 1997.
3. Otani, S., “Nonlinear Earthquake Response Analysis of Reinforced Concrete Buildings,” Lecture Notes, The Univ. of Tokyo, Japan, August 2002.