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The Experimental Examination of Gravity Load Effect on Cyclic Behavior of Steel-moment Resisting Frames

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ABSTRACT:

In real construction, the loads imposed on gravity load structures (distributed load-concentrated load) with lateral loads including earthquake, wind or landslide due to soil, consideration of all effective factors is required. In this study, the experimental examination of steel moment resisting frames that is simultaneously affected by concentrated gravity and cyclic loading will be done. The effect of gravity load on cyclic behavior of moment- resisting frame will be investigated. In a moment-resisting frame with certain dimensions, the certain concentrated load will be applied at the middle of beam and according to ATC24 protocol, the lateral cyclic displacement will be created in a frame. By drawing the cyclic diagram for imposed lateral load, the results for various seismic parameters will be evaluated. The results of experimental data and the obtained results from FEM analysis have been compared for some specimens, which had good conformity with the modeled experimental specimens. The investigation of experimental and FEM Results indicates the effect of applying gravity load on moment- resisting frame where cyclic displacement is created. The final resistance of steel frame is less than moment- resisting frame without concentrated load such that the total depreciated energy in steel-moment resisting frame without consideration of gravity load is less than 28% of moment-resisting frame with gravity concentrated load.

KEYWORDS:

Gravity load, cyclic load, moment-resisting frame, axial force, earthquake force, hysteresis, Steel-moment.

1. Introduction

One of the main structures used in residential and industrial buildings is metal moment-resisting frame with the mechanism of confrontation with earthquake force. Various studies have been carried out on the metal structures and the effect of earthquake forces on these structures; however, most studies have been theoretical and in cases that have been experimentally done, limited parameters have been studied.

In this paper, the application of concentrated gravity load with lateral displacement on a steel moment-resisting frame will be studied experimentally. In software specimens, it is tried to model all experimental conditions completely.

In order to study and evaluate and validate the behavior of steel moment-resisting frames loaded with cyclic load along with concentrated load, two different ways are used. In the first way which is the basis of the study, the intended specimens will be constructed in laboratory scale. The measurement equipment including strain gauge, drift gauge which are installed in related places. The specimens will be exposed to lateral cyclic loading and simultaneously the gravity concentrated load will be applied on the middle of beam.

The results of this method will be drawn as diagrams. The second method is numerical study of specimens with nonlinear and cyclic analyses and the obtained results will be presented as specimen graphs.

The analyses have shown that increased concentrated gravity load leads to decrease in the area under hysteresis curve. Therefore, part of absorbed energy by the frame will decrease and

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consequently, the buckling of steel moment-resisting frames will happen sooner.

2. Literature Review

In steel moment resisting frames, simultaneous application of axial and bending moment due to horizontal loads in building whether distributed loads due to ceiling load and concentrated loads imposed on frame is inevitable. During earthquake, bending moment due to drift will be created in columns along with axial force (gravity load) and in connecting beams of moment-resisting frame, the shear force, bending moment and axial force are simultaneously created. The rate of structural effect of above forces at the column and the connection point of beam to column and its effect on the resistance of moment frame has been a complicated issue that has not been yet fully studied and analyzed. Most studies in this area are related to application of cyclic load by making displacement in moment-resisting frame according to standard protocols where moment resistance of frame under cyclic load has been studied.

The investigation of parameters such as simultaneous application of service forces (distributed load with concentrated load) with drift due to earthquake force in different situations has not been carried out and if done, has been limited. There are good studies on semi-rigid connections of moment- resisting frames under cyclic loading or in bracketed frames, individually.

Yardimci and Nesrin Cuneyt Vatanseve (Abaqus Analysis User's Guide, 2012) have modeled the behavior of a frame with semi-rigid connections in cyclic loading numerically and experimentally. It is obvious that the semi-rigid moment-resisting frames under cyclic loading have completely nonlinear behavior since by imposing load, stress in steel beam gradually enters from elastic to plastic area and part of energy will be lost and depreciated in this displacement. In this paper, the experimental results of cyclic loading of a semi-rigid frame with limited- element analysis under quasi-static cyclic loading with displacement control have been investigated. The obtained hysteresis curve from the cyclic test with displacement control and hysteresis diagram of limited element presents a good model of final resistance and initial rigidity of the frame that due to gradual application of stress to screws and connection plates and other components, the structure of different types of steel frames could be divided as rigid- semi rigid- flexible steel connections.

J.A. Zepeda, A. M. Itani, R. Saha (Abedi Sarvestani, 2017) have studied the behavior of steel moment-resisting frames against horizontal axial force on beam and achieved lateral displacement theoretically and experimentally. In this paper, the cyclic behavior of steel frame, where a section of beam is designed as reduced, has been tested and investigated under the varied axial load with lateral displacement. The results indicate that when the plastic rotation is not more than 3% radian, the frame has good behavior without considerable reduction in lateral bending capacity, placing longitudinal hardeners helps transmission of axial forces and delays the local buckling.

James Newell, Chila-Ming Uang (ATC-24, 1992) studied and investigated the cyclic behavior of steel columns under axial load to column along with lateral displacement experimentally and numerically. They modeled two buildings of 3 and 7 stories and applied 20 scaled earthquake records as time history and determined the drift ratio in first story for every 20 records. For maximum drift of stories, the analysis has been performed and maximum axial force has been found. They imposed column tensile resistance equal to 35%, 55% and 75%, experimentally for each specimen of axial force and simultaneously increased the displacement in cyclic manner up to 10% of the height of column. The results of analytical models show yield and attenuation of buckling resistance of column which in most cases leads to local buckling. The experimental results showed that creation of initial stress has not significant effect on P-M behavior and in short columns lead to local buckling.

Kiarash M. Dolatshahi A, Ali Gharavi A, Sayed Rasoul Mirghad (Augusto, Rebelo, Simões, Silva & Castro, 2012) in an experimental study investigated the issue of making plastic node at the middle of beam of moment-resisting frame under seismic loading. They investigated three experimental tests for evaluation of cyclic behavior of moment-resisting frames against the special specification of the transmission of plastic node to the middle of beam. In this paper, a new approach for transmission of plastic hinges from end of beam to the center of beam is presented which could be used for new designing. The constructed specimens will be imposed to quasi-static cyclic loading; the results of analysis of limited element analysis show that it has been an appropriate idea and the plastic hinges will be transmitted to the middle of beam.

R. Montuori (Perea, Leon, Denavit & Hajjar, 2010) studied the role of vertical (gravity) loads imposed on beam in reduction of buckling resistance of plastic hinges and the distance of mentioned hinges in beam from columns; particularly, they investigated the determination of beam width reduction location (section reduction) for constitution of plastic hinges and proposed that using RBS connections could lead to optimum use of structure. In fact, the transmitted bend by beam to column decreases the same as plastic hindge resistance. Therefore, RBS connection could act as a fuse and lead to destruction of beam before column and increase of rotational capacity of beam and reduction of column section.

Mohd Fazaulnizam Bin Shamsud (Dolatshahi, Gharavi & Mirghaderi, 2018) in his thesis presented numerical analysis model of cyclic behavior of semi-rigid end connection. He performed a computational study for investigation of hysteresis model and cyclic behavior of beam to column connection. This computational model is achieved from the experimental results on various semi-rigid frame specimens. Theoretically, beam to column connection has been modified and calculated with Richard Aybot model. In the model, various parameters concerning their significance including resistance, rigidity, and energy discharge capacity have been applied. In results obtained from theoretical and experimental analysis of bending curves, the rotational angle of connections has been compared. The results show that in semi-rigid connections, energy absorption is done better than welded rigid connection and with increase in displacement, the rigidity coefficient increases and resistance decreases.

Nogueiro, P. Simões da Silva, L., Bento, R and Simõe (Zahedi, Osman & Khalim, 2013) used seismic analyses in steel frames resistance against bending to investigate the connections against hysteresis force. Their analysis show that safety against total collapse of structure could just happen with consideration of real hysteresis behavior, i.e. the presented mathematical model which is capable of prediction of destruction power and collapse could be used. Moreover, it is shown in this paper that in designing system based on bylaws and standards, the constraint of connection angles between structure and non-structural members and connections under loading of frequent earthquakes has been imposed. In Eurocode 8, certain cases have been considered in terms of connection levels and shear force applied on the connection in frequent earthquakes.

L. Mota, A. T. da Silva, C. Rebelo, L. Simões da Silva and L. de Lima (Simões, Rebelo & Mota, 2009) studied steel moment-resisting frames against bending due to seismic loading. They used Ricahrd Aybot modified model which is a complex one for investigation of rotational behaviors of steel connections. The main aim of this paper is investigation of the effect of rigidity coefficient, the resistance coefficient and the hardening effect on behavior of steel frames (MR). They showed that increase in displacement leads to increase in rigidity and hardening.

3. Protocol of applying cyclic load

Various studies have been carried out on standardization of cyclic load application. ATC24 protocol is one of the most credited protocols for application of cyclic load. In Fig. 1, the history of application of cyclic load according to ATC24 protocol has been shown. In Table 1, the number of cycles and the applied displacement are specified.

Table1. The number of procedures of applying cyclic load in protocol

Load step	Peak eformation θ	Number of cycle. n
1	0.00375	6
2	0.005	6
3	0.0075	6
4	0.01	4
5	0.015	2
6	0.02	2
7	0.03	2
Continue whit increments in θ of 0.01 and perform two cycles at each step		

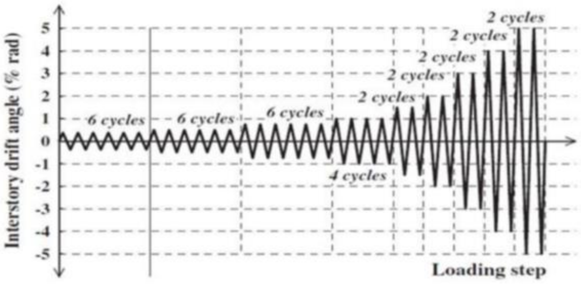

Fig. 1. The history of cyclic load application in protocol

4. The experimental study

4.1. The type of studied loading in paper

Among types of loads imposed on moment-resisting frame, this type of structures show high sensitivity to axial loading, compression loading along with bending moment and reciprocal loading. The origin of such loading is the effect of earthquake force, gravity forces and other lateral forces such as wind, landslide and etc. which could lead to buckling or local collapse of structure. In order to investigate the behavior of moment-resisting frame of experimental specimens that are almost similar in terms of dimensions and type of members with real specimens used in buildings will be constructed with appropriate scale and tested. In Fig. 7, the specimen of steel moment-resisting frame constructed in laboratory is shown. In order to apply the cyclic load, ATC24 protocol which is accepted by most researchers and scientific centers of the world is used which for intended drift in protocol, a hydraulic horizontal jack is used and measurement device which measures the amount of imposed force, displacement and stress and strain inside elements will be used.

4.2. The initial experimental specimen

In order to study the behavior of steel moment-resisting frame against cyclic loading along with application of fixed and initial concentrated force, three steel moment resisting frames have been constructed and tested according to table 3. After installation of steel moment-resisting frame at the intended place and connection of measurement tools and jack for applying cyclic force, the results have been taken from computer and after application of the coefficients related to extracted data from test, the results have been drawn as hysteresis curve diagrams.

Table 2. The specification of specimens constructed in laboratory

Specimen No.	L (mm)	H (mm)	No and type of beam profile	No and type of column profile	Amount of gravity load (N)
N1	1080	1000	IPE8	IPE8	0
N2	1080	1000	IPE8	IPE8	6500
N3	1080	1000	IPE8	IPE8	10000

In Fig. 2, N1 specimen which is experimental specimen of steel moment-resisting frame without application of gravity concentrated load is shown and in Fig. 3, N3 specimen which is experimental specimen of steel moment-resisting frame with application of gravity concentrated load of 10000 N is shown.

Fig. 2. Experimental specimen of N1 steel moment resisting frame

Fig. 3. The experimental specimen of N3 steel moment resisting frame

4.3. Experimental results

The results of testing 3 specimens of steel moment-resisting frames against cyclic loading along with application of concentrated force according to Fig. 4, 5 and 6are drawn. The comparison of the graph related to specimen without concentrated load with gravity concentrated load of 10000 N is shown in Fig. 7. The comparison of graphs shows that with increase in concentrated load, the area under the graph will decrease and the graph becomes thinner such that the numerical value of the area under Fig. 4 is 133986 (N/mm) and the area under Fig. 6 is 99632 (N-mm) which indicates 25.6% reduction of area under graph.

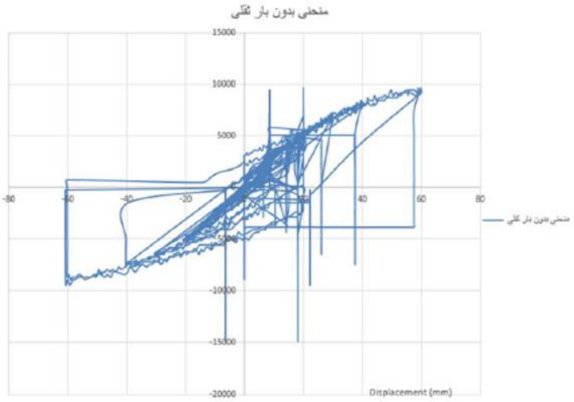

Fig. 4. Hysteresis graph of N1 experimental specimen

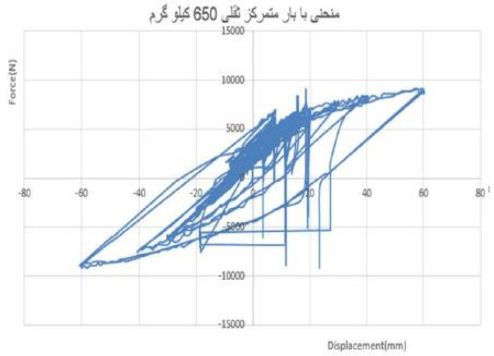

Fig. 5. Hysteresis graph of N2 experimental specimen

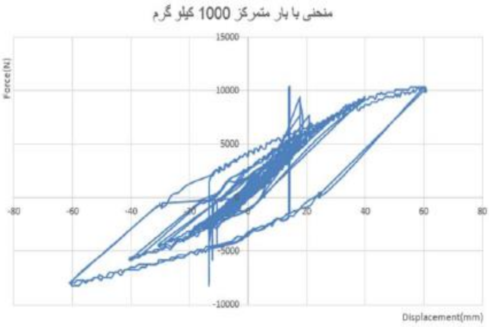

Fig. 6. Hysteresis graph of N3 experimental specimen

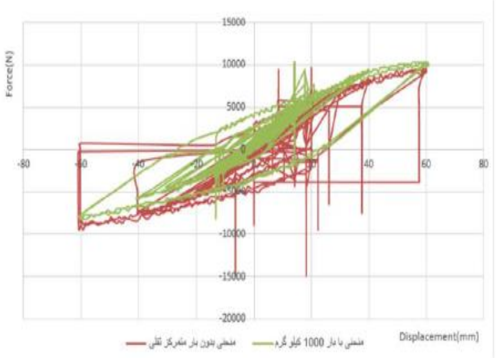

Fig. 7. Comparison of graph of N1 and N3 specimens

For comparison of parameters such as rigidity coefficient, resistance and ductility, the graph of a part of first cycle of specimens will be individually drawn, which is shown in Fig. 8 with gravity load of 10000 N with numerical specimen without gravity load. The final resistance for specimen without gravity load is 7200 N and for specimen with gravity load of 10000 N is 4120 N. The slope of curves in elastic part is almost matching, i.e. the rigidity coefficient has not significantly changed. In plastic area of the curve, with load of 10000 N, the slope has sooner negatively decreased which indicates reduction of ductility. The area under graph without gravity load is 308222 (N-mm) and the area under graph with gravity load of 10000 N is 169974 (N-mm) which indicates 44.8% reduction.

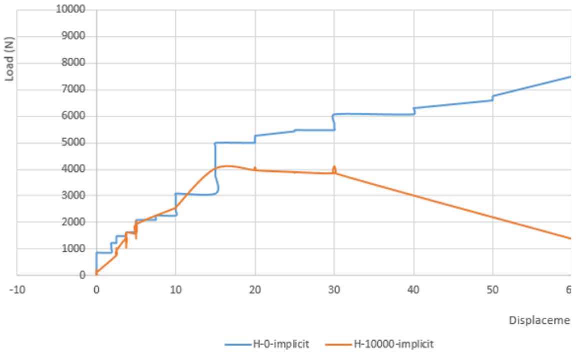

Fig. 8. The comparison of first cycle of numerical analysis curves of N1 and N3 specimens

The results of testing 3 specimens of steel moment-resisting frames against cyclic loading along with application of concentrated force according to Fig. 4, 5 and 6 are drawn. The comparison of the graph related to specimen without concentrated load with gravity concentrated load of 10000 N is shown in Fig. 7. The comparison of graphs shows that with increase in concentrated load, the area under the graph will decrease and the graph becomes thinner such that the numerical value of the area under Fig. 4 is 133986 (N/mm) and the area under Fig. 6 is 99632 (N-mm) which indicates 25.6% reduction of area under graph.

5. Numerical study program

For study, evaluation and validation of the behavior of steel moment resisting frames loaded by cyclic load along with concentrated load of intended specimens constructed in the laboratory scale, ABAQUS is used for modeling. Implicit dynamic analysis is used for nonlinear and cyclic analyses and the obtained results will be presented as comparative diagrams.

5.1. The introduction of element used in finite element modeling

One of the most significant aspects of defining a real behavior of structure is the specification of materials and the specifications of components constituting the structure. Due to nonlinear behavior of materials in large structural deformations, the nonlinear materials theory should be utilized for modeling of the constituting materials of structure. For nonlinear behavior of materials, the stress- strain curve of materials should be entered by determination of yield stress and elasticity model; while geometric nonlinear will be done with consideration of big deformations. In Fig. 9, the stress-strain curve is shown in the steel used in experimental specimens

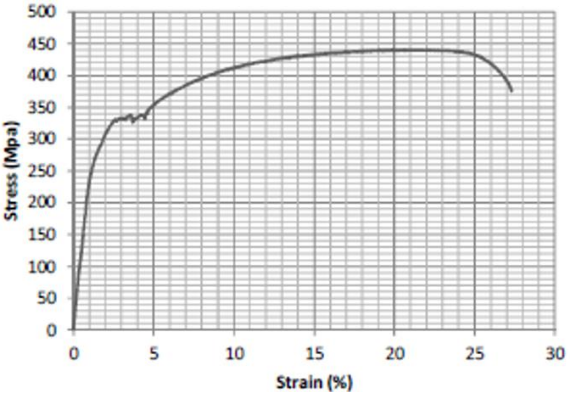

Fig. 9. The stress-strain curve in the steel used in experimental specimens

For modeling of steel moment-resisting frame, S4R element is used which is a four-node shell element, double curvature with educed integration with six degrees of freedom in each note (three degree of freedom of displacement and three degrees of freedom rotational). This element has many advantages in terms of the speed of analysis and convergence power and also capability of application in linear and nonlinear shell problems and in this element, there is the capability of big deformation analysis.

5.2. The finite element model of experimental specimens of steel moment resisting frame

The modeled specimens and the used profile is IPE8 with ST37 steel. The selected dimensions in height and bay of frame are appropriate scale of real condition. The meshing of frame with selection of appropriate density has been considered for obtaining logical results and the boundary conditions of support is fixed connection. The loading of steel frame is as horizontal cyclic loading in direction of beam axis and simultaneously with application of gravity load at the middle of beam. In Fig. 10, the modeled layout of steel moment-resisting frame which is according to the laboratory specimen is shown.

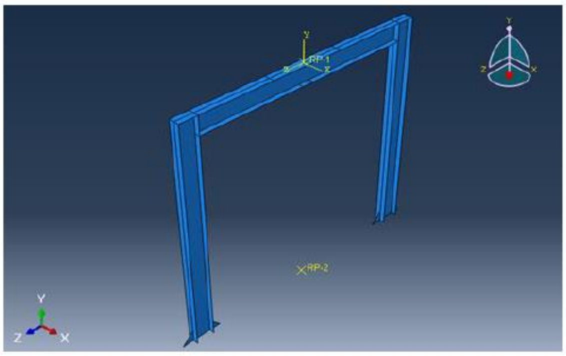

Fig. 10. The specimen of modeled steel moment-resisting frame

5.3. Finite element analysis

N1, N2 and N3 experimental specimens have been modeled according to constructed specimens with ABAQUS where the cyclic load is applied according to ATC24 protocol and analyzed using semi-static analysis where the results of limited element analysis have been extracted and drawn according to Fig. 11 (N1 software curve), 12 (N2 software curve), 13 (N3 software curve). In these analyses, it is specified that with increase in gravity concentrated load, the area of hysteresis curve will decrease. Therefore, the rate of observed energy by the frame will decrease about 28%. Therefore, the buckling of steel moment-resisting frame happens sooner. In Fig. 14, the comparison of software curve of N1 specimen with software curve of N3 specimen is shown where the difference in maximum point of imposed force where frame buckling occurs is about 20%.

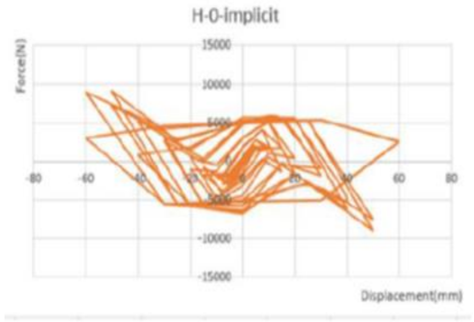

Fig. 11. Quasi-static hysteresis graph of N1 specimen

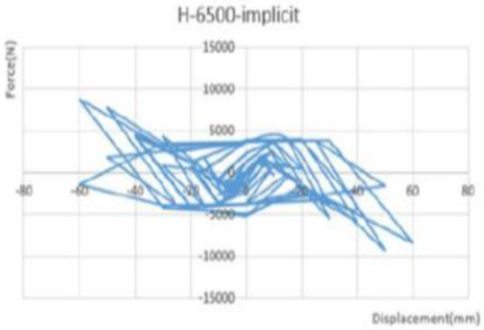

Fig. 12. Quasi-static hysteresis graph of N2 specimen

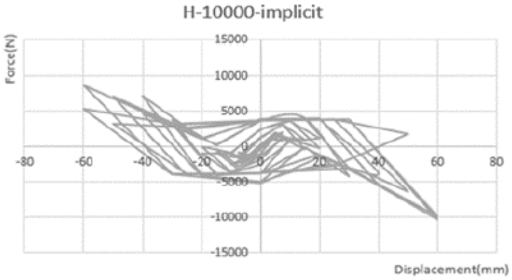

Fig. 13. Quasi-static hysteresis graph of N3 specimen

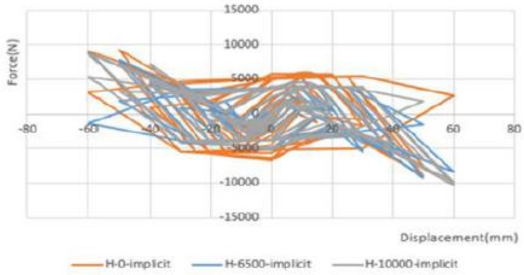

Fig. 14. Quasi-static hysteresis graph of N1, N2, N3 specimen

In Fig. 15, the curve of software energy level of N1, N2 and N3 specimens has been compared. The results show that the energy level of N1 is about 28% higher than N2 and N3 specimens. Therefore, N2 and N3 specimens buckle sooner than N1 specimen.

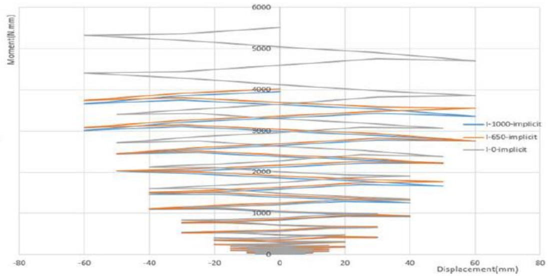

Fig. 15. The comparison of quasi-static energy level of 3 software specimen

6. The comparison of the results of numerical analysis with experimental results

The comparison of the graph related to the results obtained from software analysis with experimental results shows that the area under the graphs shows good conformity in the analytical and experimental results. In Fig. 16, the curve obtained from software and experimental analysis for N3 specimen has been compared. For investigation of the mentioned case, in Fig. 17, part of first cycle of experimental specimen N3 with part of first cycle of graph of numerical specimen N3 has been compared. The slope of graph related to numerical results in elastic part is about 5% more and the final resistance of both is almost the same; however, reduction of resistance with negative slope started sooner in numerical specimen and the area under numerical graph is about 169974 (N-mm) and the area under graph of experimental specimen is 177096 (N-mm) which has a difference of about 4% which indicates that the results of numerical analysis match with the results of experimental results.

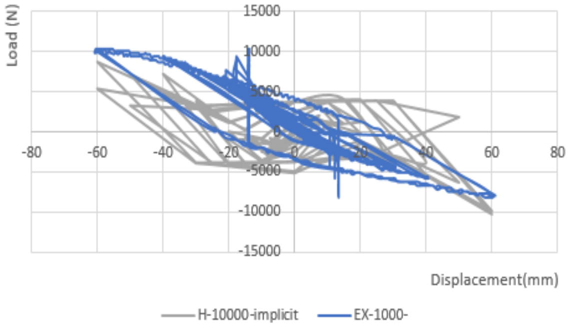

Fig. 16. The comparison of hysteresis curve of N3 specimen

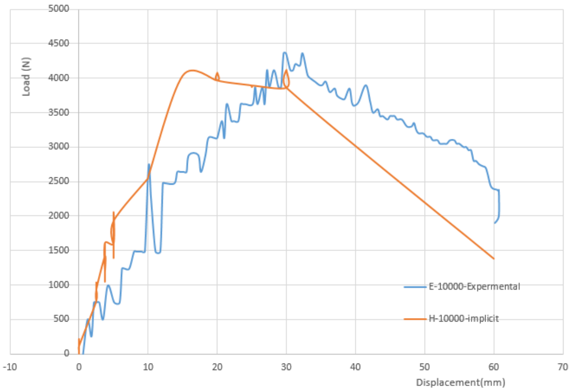

Fig. 17. The comparison of part of first cycle of graphs of the results of numerical analysis and experimental analysis of N3 specimen

7. Results

The results of experimental data with the results obtained from software analysis for several initial specimens show that the results of experimental specimens match with the results of modeling. The investigation of experimental data and software data indicate the effect of applying gravity load on moment-resisting frame with cyclic displacement. The results could be summarized as follow:

1. With application and increase of concentrated gravity force, the area under force-displacement curve decreases where reduction of area leads to reduction of absorbed energy to 28% which decreases due to buckling resistance of steel moment resisting frame.
2. With application and increase of concentrated gravity force, the area under force-displacement curve becomes irregular and the slope of curve at plastic area becomes steep which leads to reduction of ductility and rapid collapse of structure.
3. With application and increase of concentrated gravity force in force-displacement curve, the initiation of plastic area happens sooner and as a result of failure in return or extraction of forces in structure happens sooner.
4. With application and increase of concentrated gravity force in force-displacement curve, the curve slope in elastic area doesn't significantly changes; i.e. the rigidity coefficient in elastic area remains fixed.
5. With application and increase of concentrated gravity force in the displacement curve, the beginning of the plastic region occurs earlier, resulting in non-reversibility with the removal of the forces involved in the structure earlier.
6. The application of gravity load reduces about 30% bending anchor at the foot of the columns.

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