AN EXPERIMENTAL STUDY ON INELASTIC RESPONSE BEHAVIOR OF STEEL FRAME WITH EXPOSED-TYPE STEEL COLUMN BASE UNDER AXIAL LOADING

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ABSTRACT :

In this paper, the inelastic response behavior of steel frame with exposed-type steel column base is studied pseudo-dynamically and numerically. Herein, the sub-structure pseudo-dynamic response tests are performed with or without axial loading subjected to the ground acceleration. An exposed-type column base is a substructure portion tested. Test specimens are composed of two types of thickness of base plate. From the test results, it can be said that the ultimate state of column base is divided into two types, namely the bolt failure mechanism and the base plate failure mechanism. The hysteresis loop of thick base plate is very close to an ideal progressive slip model, and the one of thin base plate is close to degrading stiffness model. The difference of the response behavior of fictitious frame with or without axial loading is not large. However, in the case of thin base plate, the response behavior of column base with axial loading is larger than the case without axial loading. And also, the completely numerical response analysis based on typical hysteresis rules of column base is performed and compared with response test results.

KEYWORDS: Exposed-type column base, Steel structures, Pseudo-dynamic response test, Numerical response simulation, Hysteresis model

1. INTRODUCTION

A column base is the important part of a structure, which transfer the loading to the foundation. And an exposed-type column base is widely used in a low-rise steel building or a plant structure. They deform under shear forces and bending moments, when the structure is subjected to lateral forces. Their behavior under such loading strongly affects the overall behavior of the structure. To understand the characteristics of dynamic behavior of the column base, several researches have been conducted so far. However, these studies are mostly restricted to the strength, stiffness and ductility of column base itself. On the other hand, the studies about the characteristics of the dynamic behavior of the frame with column base have been conducted numerically; however, it can be said that the experimental studies about that frame have not been conducted enough.
In this paper, the sub-structure pseudo-dynamic response test on steel frame with exposed-type column base is conducted. The exposed-type steel column base is a substructure portion tested. The test specimen is composed of two types of thickness of base plate, which is designed to generate the typical failure mode of column base.
Additionally, the numerical simulation based on two types of hysteresis rule, progressive slip and degrading stiffness model, is performed and compared with response test results.

2. OUTLINE OF SUB-STRUCTURE PSEUDO-DYNAMIC RESPONSE TESTS

2.1. Hybrid Structural Model Adopted in Pseudo-dynamic Response Test

A hybrid structural model adopted in the following sub-structure pseudo-dynamic test is illustrated in Figure 1. An exposed-type steel column base is a substructure portion tested, and the half of this is actually loaded in a pseudo-dynamic test. The fictitious column of frame is assumed to be in elastic range. Moment and rotation of column base are obtained from the actuator load cell and displacement gage during loading test, and the moment and rotation of fictitious column are obtained from the numerical simulation that is performed simultaneously in on-line computer.

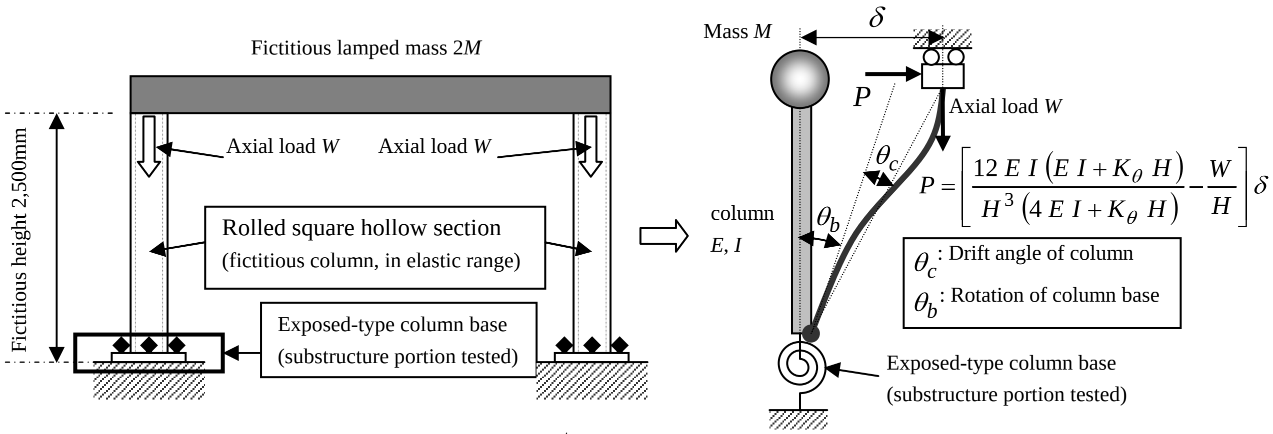


Figure 1 Hybrid structural model of 1st story steel frame with exposed-type column base

2.2. Detail of Test Specimen and Material Property

The test specimens are fabricated of cold-formed square hollow steel column, and it is made of JIS grade STKR rolled square hollow section. Its effective height is 1,500mm. The column is designed to be in elastic range during loading test. The base plate size is 300 x 300 x 9 and 300 x 300 x 9.

The bolts are tightened by torque wrench so that pretension at each bolt is 500 kgf-cm. All of the bolts is fastened double nut. The base plate is anchored using eight ϕ12 all screw bolts. Figure 2 shows the detailing of specimen. The properties of base plate and bolt are summarized in Table 1 and Table 2, respectively.

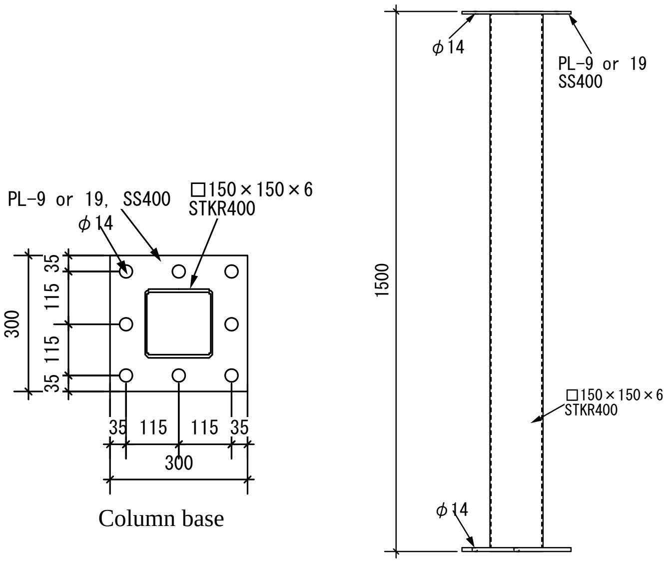


Figure 2 Detail of test specimen

Table 1 Mechanical properties of bolt

Yield strength	Maximum strength	Yield strain	Elongation
41.22kN	58.46kN	0.67%	7.10%

Table 2 Mechanical properties of base plate

Thickness of base plate	Yield stress	Tensile stress
t=9mm	270N/mm^2	450N/mm^2
t=19mm	250N/mm^2	430N/mm^2

2.3. Test Setup and Measuring Arrangement

The system composed of those elements is setup as cantilever column as shown in Figure 3. Herein, the column is the jig to load the bending moment to the column base. And also the hydraulic actuators for lateral and axial loading are attached at the top of the column as shown in Figure 3. Displacement gages are attached to the hydraulic actuator to measure the displacement at the top of the column. An aluminum frame is attached around the lower part of the column, and displacement gages on each side of that frame are placed to measure the rotation of column base directly. On the top of each bolt, displacement gages are attached to measure the uplift of bolts. Restoring lateral force of specimen is obtained from the actuator load cell, and then the moment at column base can be also obtained after the restoring force of specimen times the effective height of specimen. An aluminum frame to measure the rotation of column base is presented in Figure 4.

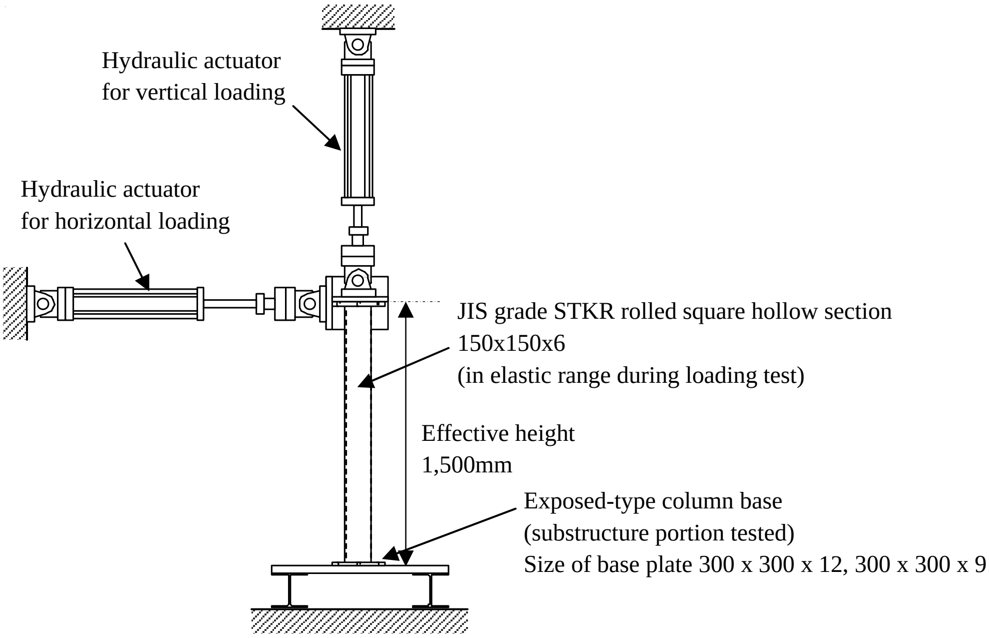


Figure 3 Test setup

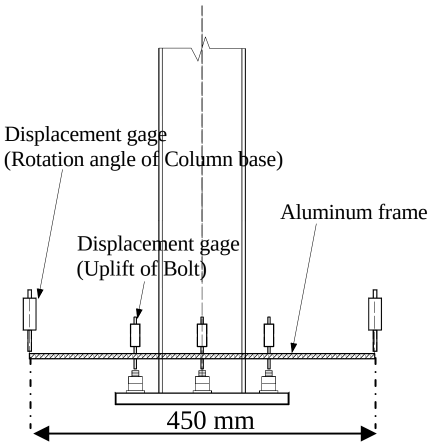


Figure 4 Measuring equipment for rotation of column base and uplift of bolt

2.4. Test Case and Input Earthquake Wave

In this paper, the hybrid analytical model as shown in Figure 1 is examined pseudo-dynamically. Fictitious lamped mass is placed at the top of each fictitious elastic column. Natural period is 0.3 sec if column base is assumed as fixed support condition. And then, the fictitious inertia weight of frame is 4,130 kg. In case of consideration of axial loading, the weight 4,130kg of the fictitious frame is loaded during pseudo-dynamic test. The fictitious height of frame is 2,500mm, and the fictitious damping is taken 2.0%. The properties of hybrid

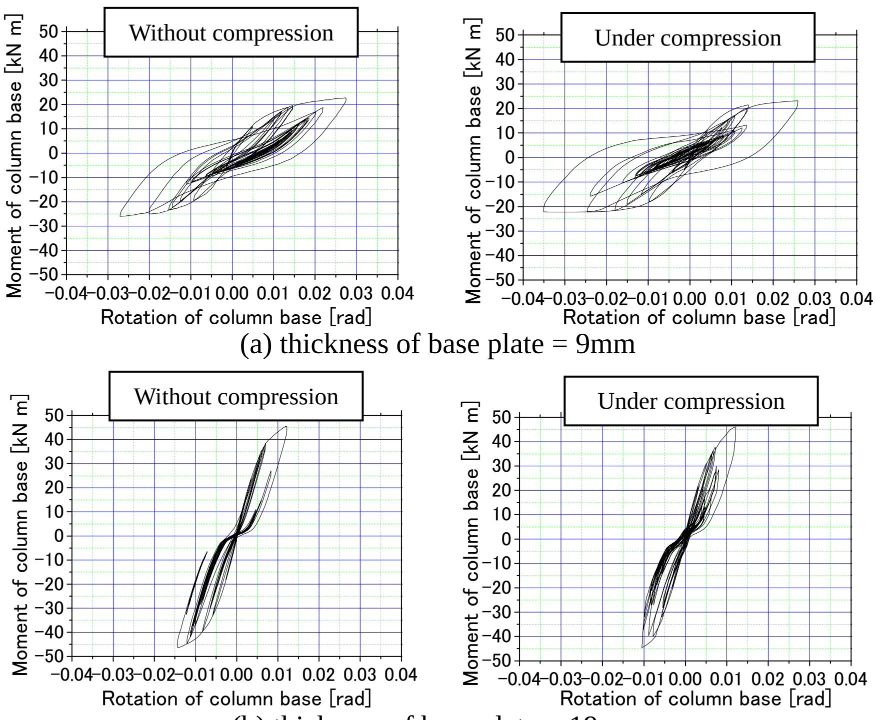
analytical model are shown in Table 3.
Pseudo-dynamic response test is performed on the above-mentioned hybrid structure system subjected to ground acceleration record of El Centro NS 1940. The peak ground acceleration of the input wave is scaled to 4,767 mm/sec^2. During earthquake response test, the duration is 15 sec, and time increment for numerical integration is 0.005 sec.

Table 3 Properties of hybrid analytical model (with 2 fictitious columns)

Condition of support of column base	Fix	Pin	Exposed-type column base			
			Thin base plate (t=9mm)		Thick base plate (t=19mm)	
			No compression	Compression	No compression	Compression
Fictitious inertia mass	2*M* (W=Mg =4,130kg, g is gravitational acceleration)					
Fictitious floor height	*H* = 2,500mm					
Moment inertia of fictitious column	$I = 1.15\text{x}10^7$ mm^4					
Elastic rotation stiffness of 1-column base	--	--	2,250kN m/rad	4,320kN m/rad	5,800kN m/rad	7,140kN m/rad
Lateral stiffness of hybrid fictitious frame	3,620kN/m	905kN/m	1,920kN/m	2,360kN/m	2,550kN/m	2,680kN/m
Natural period	0.30sec	0.60sec	0.41sec	0.37sec	0.36sec	0.35sec
Fictitious damping ratio	*h* = 2%					

3. TEST RESULTS

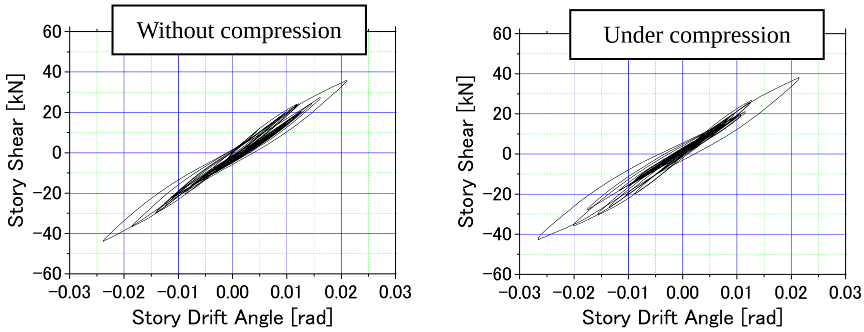
The pseudo-dynamic response tests are conducted in case of thickness 9mm and 19mm of base plate with or without axial loading. The hysteresis loops of moment vs. rotation of column base are shown in Figure 5. The hysteresis loops of story drift angle vs. story shear of fictitious frame are shown in Figure 6. The cumulative rotation curves of column base are shown in Figure 7. In this case, any bolts are not broken, however, an elongation of any bolt is observed.



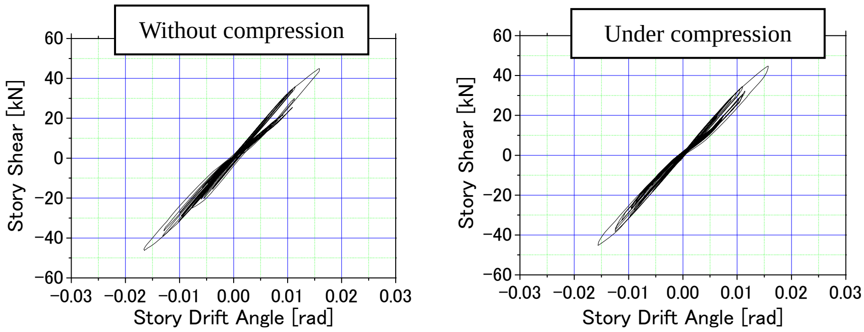
(a) thickness of base plate = 9mm

(b) thickness of base plate = 19mm

Figure 5 Hysteresis loops of moment vs. rotation of column base of test result

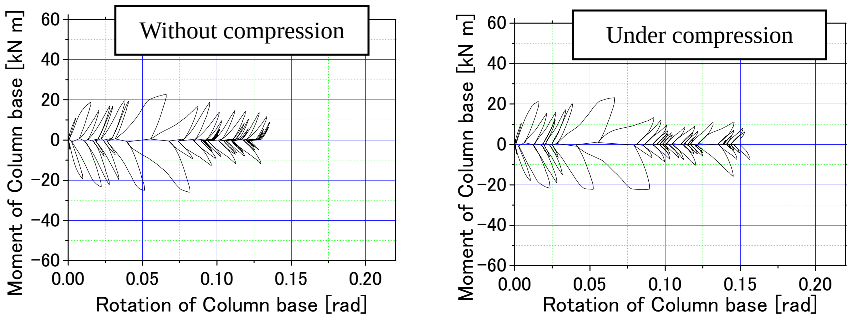


(a) thickness of base plate = 9mm

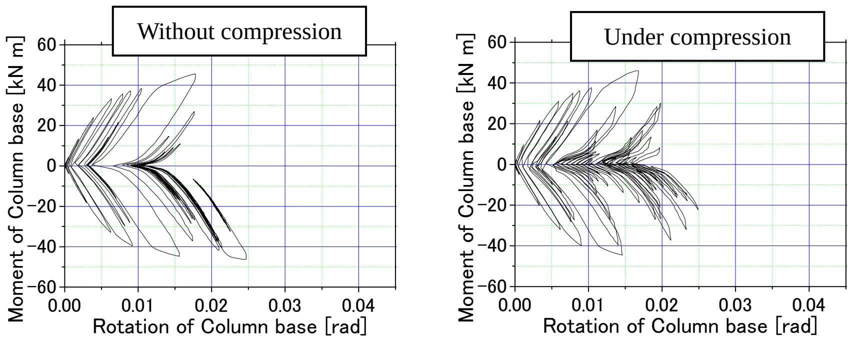


(b) thickness of base plate = 19mm

Figure 6 Hysteresis loops of story drift vs. story shear of column base of test result



(a) thickness of base plate = 9mm



(b) thickness of base plate = 19mm

Figure 7 Cumulative rotation curve of column base of test result

From these test results, it can be said that the ultimate state of column base is divided into two types, according to their mechanical characteristics, namely the bolt failure mechanism and the base plate failure mechanism.
From the results of Figure 5, the hysteresis loop of thick base plate is very close to an ideal progressive slip model, and the hysteresis loop of thin base plate is close to a degrading stiffness model. From the results of Figure 6, the plastic deformation of fictitious frame is not large; on the other hand, the large plastic deformation

can be observed on column base as shown in Figure 5. Therefore, the remarkable plastic deformation on the global behavior of frame with exposed-type column base may not be occurred. However, the dominant plastic deformation may be progressed only on the column base even if the hysteresis loops of story drift vs. story shear show that the frame may behave without large plastic deformation. From the observation of test result of bolts, the remarkable elongations of bolts are observed in case of each thickness type of base plate. The uplift of the bolt at the middle is higher compared with the bolts at the corner. In case of thick base plate, the bolts at the corner fail and its maximum axial strain reaches to 2.30%. On the other hands, in case of thin base plate, the bolts at the corner don't fail and its maximum axial strain reaches to 0.64% (yield strain of bolt is 0.67%). From these results, the base plate yielding is dominated in case of thin base plate, and the bolt yielding is dominated in case of thick base plate.

4. NUMERICAL RESPONSE ANALYSIS

4.1. Skeleton Curve for Column Base

The skeleton curves for exposed-type steel column base are calculated by the limit analysis and the design formula of AIJ recommendation. Furthermore, the envelopes of the hysteresis loops of response test results are adopted for the skeleton curve.

4.2. Hysteresis Rule for Column Base

The following two types of hysteresis rule for the column base are adopted herein.
(1) Progressive slip model in case of thick base plate
(2) Degrading stiffness model in case of thin base plate

4.3. Comparison of Response Results

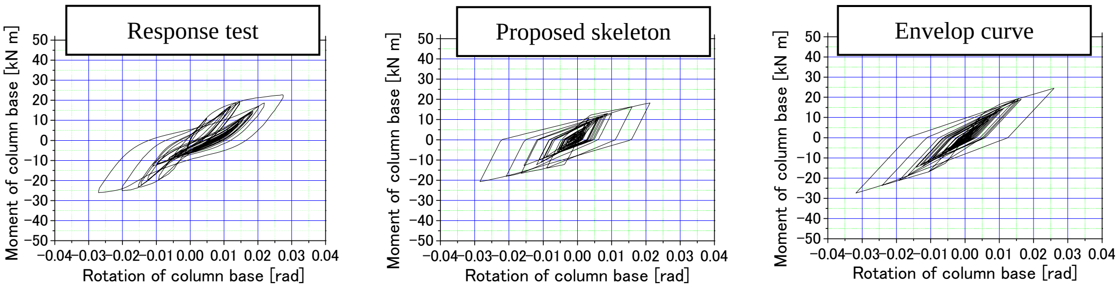
Completely numerical response analyses based on the previous hysteresis rules for the column base are performed. Figure 8 shows the hysteresis loops of moment vs. rotation of column base, and Figure 9 shows the hysteresis loops of shear force vs. story drift angle of the fictitious frame.
The results of hybrid simulation test observed and completely numerical response analysis based on the skeleton curve of the envelope of test result look very similar to each other. On the other hands, the proposed standard skeleton curve for column base, in particularly the strength and stiffness, is smaller than the test results. Further, the behavior of column base strongly affects the overall behavior of the structure. It may be necessary to improve the standard skeleton curve and the formula of strength and stiffness of column base. However, the method of numerical response analysis can simulate the inelastic response behavior of the frame with exposed-type column base.

5. CONCLUSION

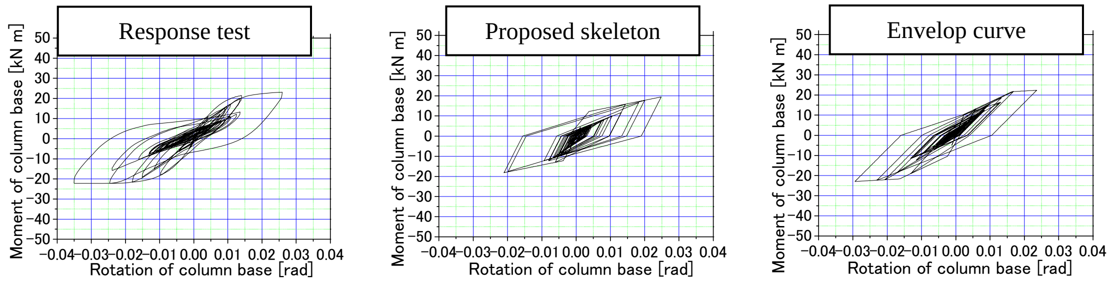
In this paper, the sub-structure pseudo-dynamic response test on steel frame with exposed-type steel column base is described. The test specimen is composed of two types of thickness of base plate. The moment and rotation of exposed-type column base can be obtained from loading test part, and the system of loading test is setup as cantilever column. A hybrid structural model adopted in the sub-structure pseudo-dynamic test is 1st story steel frame, and the moment and deformation of fictitious column are obtained from the numerical simulation that is performed simultaneously in on-line computer.
The response test results show two different types of hysteresis loop on column base. The hysteresis loop of thick base plate is very close to an ideal progressive slip model, and the one of thin base plate is close to a degrading stiffness model. Furthermore, the large plastic deformation of fictitious frame may not be occurred, on the other hand, the large plastic deformation is observed from the response hysteresis loop of column base. Therefore, the remarkable plastic deformation on the global behavior of frame with exposed-type column base may not be occurred. However, the dominant plastic deformation may be progressed only on the column base even if the hysteresis loops of story drift vs. story shear show that the frame may behave without large plastic

deformation. And also, the remarkable elongations of bolts are observed in case of each thickness type. The uplift of the bolt at the middle is higher compared with the bolts at the corner. In case of thick base plate, the bolts at the corner fail. On the other hands, in case of thin base plate, the bolts at the corner don't fail. From these results, the base plate yielding is dominated in case of thin base plate, and the bolt yielding is dominated in case of thick base plate.

Additionally, the numerical response analysis based on two types of hysteresis rule of steel column base, progressive slip and degrading stiffness model, is performed. From the results of numerical simulation, the method of numerical response analysis can simulate the inelastic response behavior of the frame.

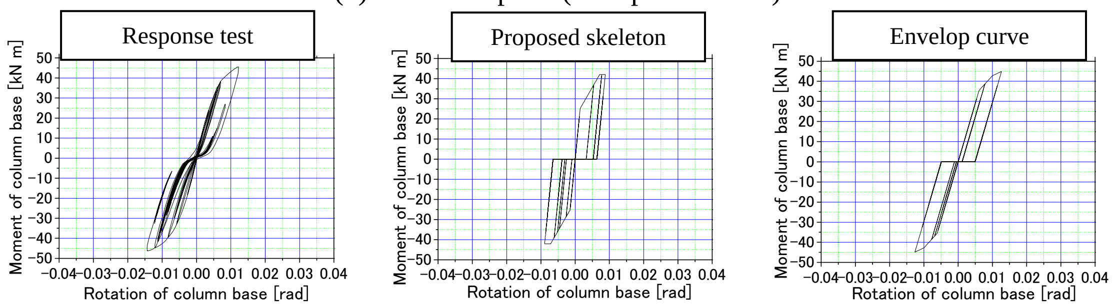


(a) Without compression

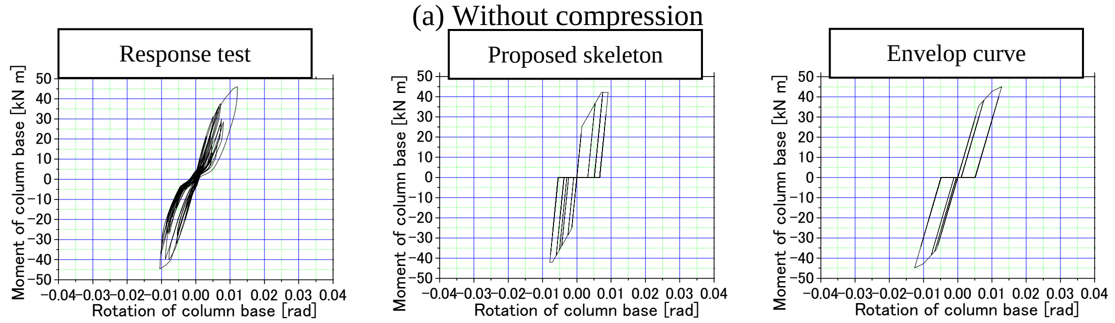


(b) Under compression

(1) Thin base plate (base plate failure)



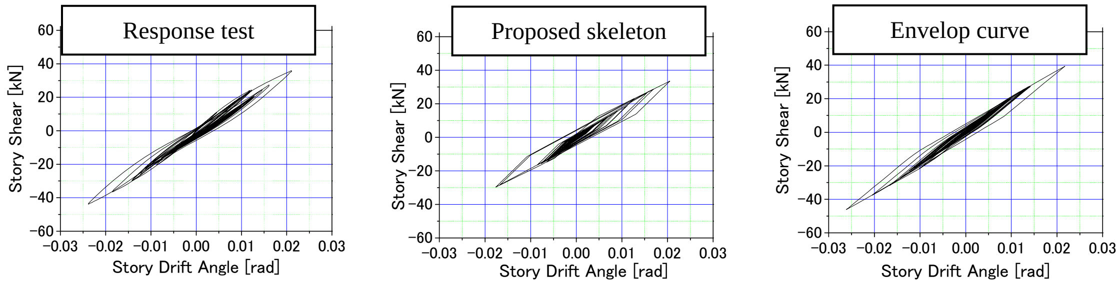
(a) Without compression



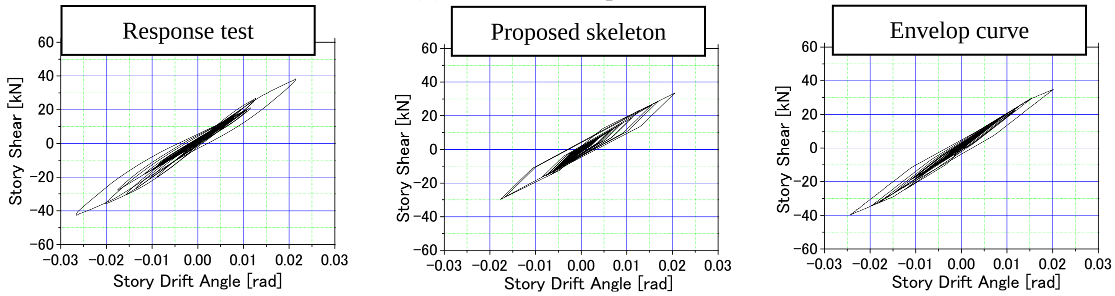
(b) Under compression

(2) Thick base plate (bolt failure)

Figure 8 Comparison of hysteresis loops of moment vs. rotation of column base

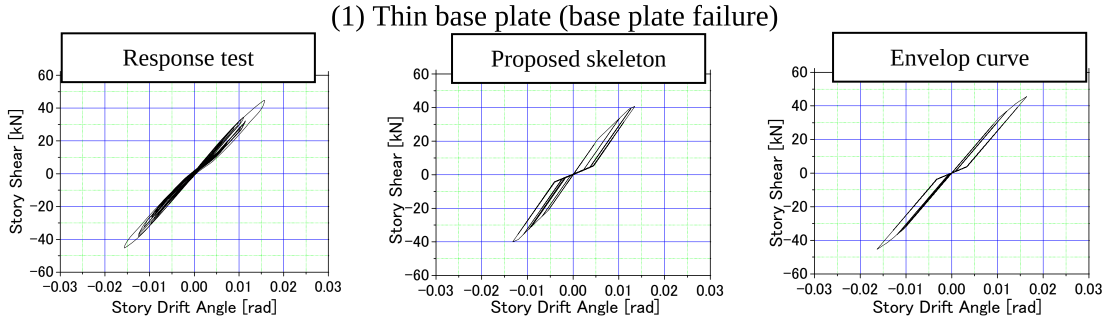


(a) Without compression

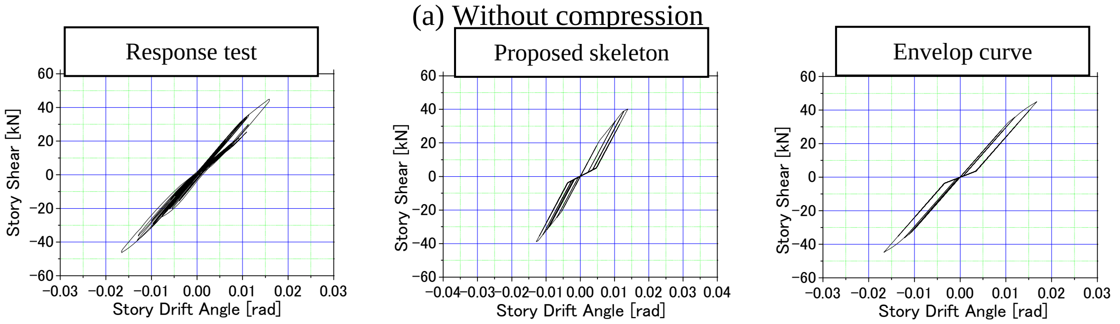


(b) Under Compression

(1) Thin base plate (base plate failure)



(a) Without compression



(b) Under compression

(2) Thick base plate (bolt failure)

Figure 9 Comparison of hysteresis loops of shear force vs. story drift angle of frame

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