VIBRATION TEST OF A FRAME WHICH HAS AN OIL-DAMPER BRACE

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SUMMARY

We developed a new type seismic control device that was known to oil damper bracing system (ODB-system). ODB-system is the system that sets up oil damper directly on rahmen as a brace. Until now, we have carried out the test of oil damper itself to grasp behavior and performance. Then we carried out frame vibration test of ODB-system. This paper reports the testing results, proposes an analysis model for ODB-system and analysis method for ODB-system, and verifies the validity of them by comparing analysis results with testing results.
As a result, it is confirmed that ODB-system moves normally, exhibited stabilizing damping force, and do not give needless stress on the frame. It was clarified that ODB-system can be applied to actual structural design with using by Maxwell model by comparing analytical results to the test.

INTRODUCTION

Recently, it is necessary for us to maintain of safety and function of buildings against external forces such as earthquake and wind. Moreover, improvement of the habitability are demanded. We think that seismic control structures are effective in order to realize these demands based on the economy. It is more important to advance the development of effective and practical seismic control devices to the buildings on the point of structural designer. As there has been various seismic control devices, we developed a new type device with oil damper bracing system (ODB-system) which sets up oil damper on rahmen as a brace. ODB-system was developed from next five points as followings,

1. Easy response analysis with clear damping property.
2. Not disturbed by temperature.
3. Stable damping performance from small to large amplitude.
4. Free from maintenance.
5. Damping force dose not give a bad influence on the structure.

But, it is necessary for us to grasp its motion and performance in order to adapt it to the buildings. Until now, we carried out the test of a oil damper itself [1,2,3] and grasped the behaviors and performances on it. Then, we have carried out the frame vibration test with it. This paper reports for all of the test. We also carried out two kinds of analysis. One was a vibration analysis with one mass and another was 2-dimensional frame for ODB-system in order to apply ODB-system to the structural design.

2. TEST OUTLINE

2.1 Test frame outline:

We permormed the tests for two kinds of frames. One type was ODB-system (Figure 1-(a)). Another type was K-shaped bracing system which has a oil damper between the bottom of V shaped brace and corner of the frame

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(Figure 1-(b)). Both test frames were 1/2 scale models. The dependence characteristics on velocity can be expressed by the damping performance (damping force: Q^* and velocity: V^*) shown in Figure 2. There is a relief valve with considering the fail safe. A relief valve opens to the load more than predetermined, and it is considering as the bi-flow characteristic. Damping force is controlled with considering bi-flow characteristics. The damping characteristics adapted on the test frames is primary damping coefficient:C_1^*(= 2.5t・sec/cm) and secondary damping coefficient: C_2^* (=0.0082C_1^*) after setting up with relief damping force: Q_1^*.

2.2 Test Method:

The test was carried out with using reaction frame owned by Nippon Institute of Technology. The test frame was set up into the reaction frame, and servo actuator was set up at left upside panel point. The servo actuator has the capability in the actuator are 3.0t as the maximum load and 10.0cm as the maximum stroke. Moreover, circle mark number in Figure 1 appear the points of load cell, displacement meter, and strain gauge set up at a column and a girder. The relation between the point number and kind of measurement are showed in Table 1. In the test, the vibration force was applied at the right upper corner of the test frame with a servo actuator in the conditions as followings,

1. Loading cycle : 0.5～6.0seconds (at 0.5seconds)
2. Loading wave pattern : Sine wave
3. Maximum load : 3.0t

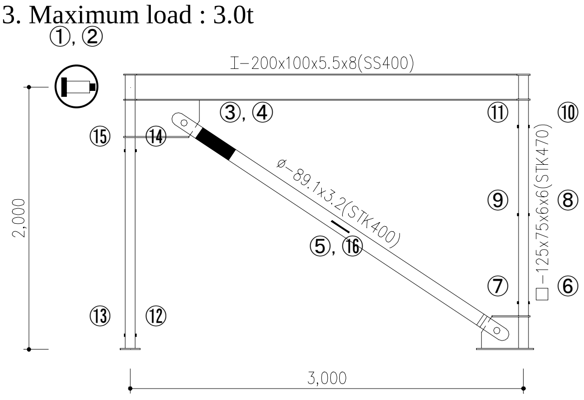


Figure 1-(a): Test frame of ODB-system

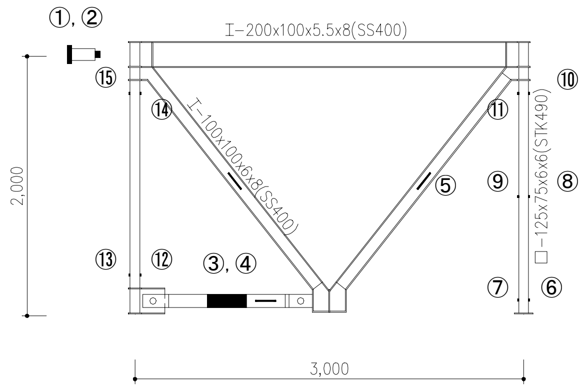


Figure 1-(b): Test frame of K-shape bracing system

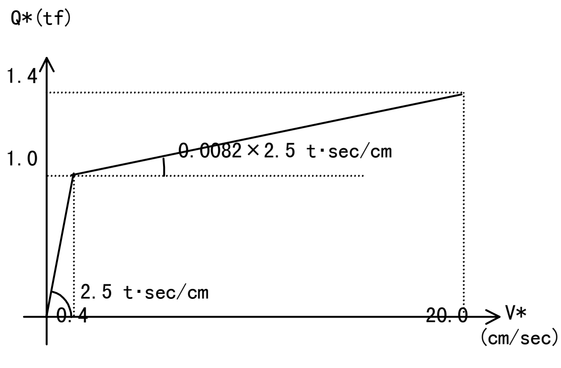


Figure 2: Damping performance

Table 1: Measurement points

Measurement point		,þˆÐm		
		,ŋça	K-shape	Free vibration
Servo actuator	Load cell	‡@	‡@	‡@
Servo actuator	Disp. meter	‡A	‡A	‡A
Damping forces on the damper	Load cell	‡B	‡B	|
Damper displacement	Disp. meter	‡C	‡C	|
Total displacement at the brace	V	‡O	|	|
Strain of brace	Strain gauge	‡D	|	|
Strain of left column base	V	‡E	‡E	‡E
V		‡F	‡F	‡F
Strain of inflection point of left column	V	‡G	‡G	‡G
V	V	‡H	‡H	‡H
Strain of left column top	V	‡I	‡I	‡I
V	V	‡J	‡J	‡J
Strain of right column base	V	‡K	‡K	‡K
V	V	‡L	‡L	‡L
Strain of right column top	V	‡M	‡M	‡M
V	V	‡N	‡N	‡N
Right side of K-shape brace force	Strain gauge	|	‡D	|

3. TEST RESULTS

3.1 Free Vibration Test:

In the free vibration test, loading force 3.0t was performed at first on the right top of the frame with the servo actuator and this performed loading was removed instantly. Two kinds of tests were performed on the same frame. One was the test for the frame with a damper and another was without damper. The diagram for displacement in the time history is showed in Figure 3 at each test in the frame. The natural period on the ODB-system is showed as 0.64 seconds. The damping ratio is showed as 0.3% without damper and is showed as 6.5% with damper. On the other hands, the natural period on the K-shape bracing system is showed as 0.76 seconds. The damping ratio is showed as 0.3% without damper and is showed as 6.5% with the damper. There is difference about twenty times for the damping ratio with the damper and without damper.

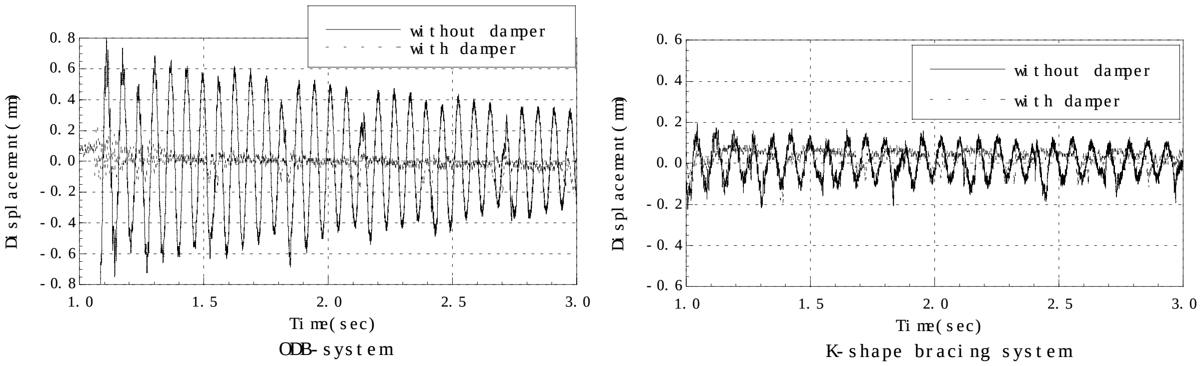


Figure 3: Diagram for displacement in the time history

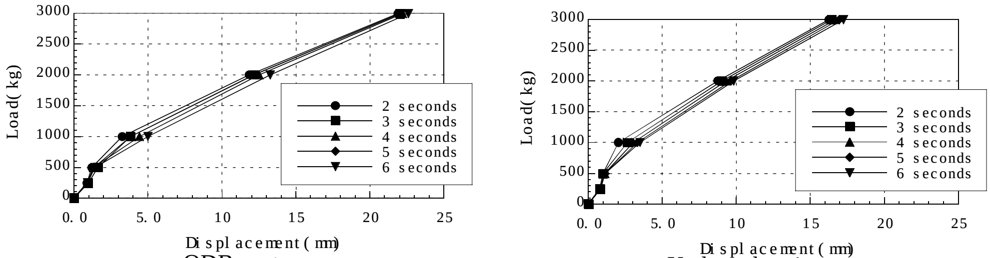
3.2 Dynamic Vibration Test:
The relationship between loading values at the servo, displacement at the damper, damping forces on the damper and total displacement at the brace is showed in the Table 2. The same relationship at K-shape bracing system in Table 3. The relationship at between loading values at the servo and displacements at the place where servo loading performed on the frame in the time history is showed in Figure 4. According as the loading values at the servo increase, difference of displacement on both test frames also increase and displacement on both test frames differs by 20% when servo loading is maximum:3.0t.
The relationship between loading values and values in the stress at point number 14 in the time history is showed in Figure 5. The values in the stress in ODB-system are about 40% smaller then those in K-shape bracing system. It is clear as a result that ODB-system does not give needless stresses at the frame and is more efficient for the damping force.

Table 2: Frame test results on ODB-system

Data No.	Load cycle (sec)	Target Load (kg)	Servo Disp. (mm)	Servo Load (kg)	Damper Disp. (mm)	Damping force on damper(kg)	Total Disp. Of brace(mm)
C.012	6.0	250	0.93	256.20	0.26	243.10	0.27
C.013	6.0	500	1.45	501.90	0.61	498.80	0.63
C.014	6.0	1000	4.99	1001.90	3.28	831.30	3.34
C.015	6.0	2000	13.25	2007.50	9.70	1012.60	9.78
C.001	6.0	3000	22.59	2991.50	17.06	1040.50	17.77
C.016	5.0	250	0.91	251.40	0.26	236.90	0.27
C.017	5.0	500	1.38	501.90	0.54	501.20	0.58
C.018	5.0	1000	4.75	1005.70	3.11	868.60	3.14
C.019	5.0	2000	12.93	2007.50	9.43	1018.60	9.53
C.003	5.0	3000	22.40	2982.50	16.93	1037.40	16.97
C.020	4.0	250	0.98	256.20	0.27	238.10	0.28
C.021	4.0	500	1.33	504.80	0.51	503.10	0.51
C.022	4.0	1000	4.44	1001.70	2.83	918.80	2.88
C.023	4.0	2000	12.50	2007.50	9.18	1024.80	9.30
C.005	4.0	3000	22.22	2992.00	16.88	1065.50	16.99
C.024	3.0	250	1.01	253.30	0.51	220.60	0.57
C.025	3.0	500	1.66	502.80	0.84	451.90	0.87
C.026	3.0	1000	3.83	1005.70	2.43	953.10	2.51
C.027	3.0	2000	12.16	2007.50	8.95	1040.40	9.08
C.007	3.0	3000	22.03	2992.00	16.69	1115.50	16.84
C.028	2.0	250	0.91	249.50	0.34	221.90	0.34
C.029	2.0	500	1.21	502.80	0.48	490.00	0.52
C.030	2.0	1000	3.25	1005.50	1.95	990.50	2.01
C.031	2.0	2000	11.84	2007.50	8.60	1081.50	8.78
C.009	2.0	3000	21.91	3001.50	16.50	1190.50	16.54
C.033	1.0	250	0.78	255.20	0.21	243.70	0.23
C.034	1.0	500	1.04	500.00	0.33	506.30	0.36
C.035	1.0	1000	2.59	1002.00	1.43	1021.60	1.53
C.037	6.0	1000	9.41	1002.00	<- resuts of free vibration test		

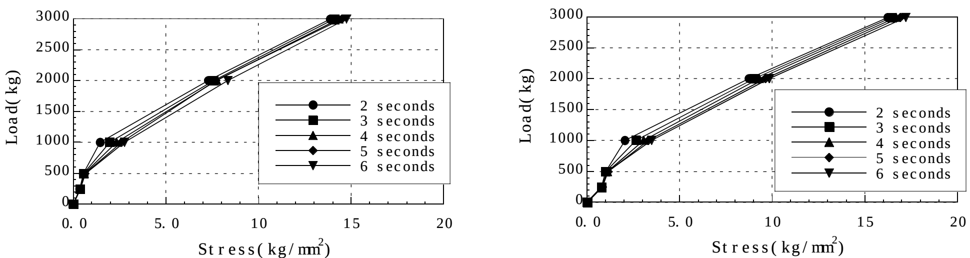
Table 3: Frame test results on K-shape bracing system

Data No.	Load cycle (sec)	Target Load (kg)	Servo Disp. (mm)	Servo Load (kgf)	Damper Disp. (mm)	Damping force on damper(kgf)	Total Disp. Of brace(mm)
D.001	6.0	250	0.79	253.30	0.16	206.90	0.43
D.002	6.0	500	1.13	501.90	0.41	425.00	0.70
D.003	6.0	1000	3.51	1005.80	2.42	793.70	2.58
D.004	6.0	2000	9.84	1998.00	7.93	1001.10	8.24
D.005	6.0	3000	17.22	3011.00	14.43	1028.10	15.13
D.007	5.0	250	0.80	252.40	0.15	203.10	0.25
D.008	5.0	500	1.09	499.00	0.39	421.00	0.45
D.009	5.0	1000	3.33	1005.50	2.25	818.80	2.42
D.010	5.0	2000	9.63	2007.50	7.73	1006.30	8.13
D.011	5.0	3000	16.94	3001.50	14.25	1034.30	14.94
D.012	4.0	250	0.79	249.50	0.17	201.90	0.25
D.013	4.0	500	1.07	502.80	0.34	429.40	0.41
D.014	4.0	1000	3.05	1002.00	2.00	856.30	2.15
D.015	4.0	2000	9.31	2007.50	7.45	1015.60	7.83
D.016	4.0	3000	16.72	2998.00	14.06	1046.50	14.75
D.017	3.0	250	0.77	249.50	0.18	203.10	0.23
D.018	3.0	500	1.01	503.80	0.28	430.60	0.38
D.019	3.0	1000	2.07	1005.50	1.63	890.60	1.68
D.020	3.0	2000	9.03	1998.00	7.20	928.30	7.53
D.021	3.0	3000	16.46	3001.50	13.87	1093.50	14.50
D.022	2.0	250	0.75	252.40	0.13	206.90	0.23
D.023	2.0	500	0.98	500.90	0.23	431.90	0.31
D.024	2.0	1000	2.04	1001.80	1.08	909.40	1.18
D.025	2.0	2000	8.75	1998.00	6.88	1049.50	7.26
D.026	2.0	3000	16.25	3001.50	13.62	1165.50	14.19
D.027	1.0	250	0.75	251.50	0.14	205.60	0.22
D.028	1.0	500	0.96	504.80	0.22	431.90	0.31
D.029	1.0	1000	1.59	1005.70	0.64	893.70	0.72
C041	6.0	1000	7.82	997.80	<- results of free vibration test		



ODB-system K-shape bracing system

Figure 4: Relationship between loading values at the servo and displacement



ODB-system K-shape bracing system

Figure 5: Relationship between loading values at the servo and values in the stress

4. ANALYSIS OF ESTIMATING TESTING VALUE

4.1 Analysis with One mass system

4.1.1 Analysis Model:

The model with a dashpot would be considered as inadequate. Since the ellipse was able to check the tendency to be come long and slender as a form in the loop for damping forces and displacements obtained with dynamic test for oil damper itself [1,2]. As a result, analysis model for ODB-system was used with Maxwell model showed in Figure 6. The stiffness with Maxwell model is the whole stiffness for ODB-system. K_T^*(=25.1t/cm) is the value compounded in steel stiffness K_B^*(=77.9t/cm) and oil compression rigidity K_d^*(=37.0t/cm). The equation for K_T^*

is given by next expression;

$$\frac{1}{K_T^*}=\frac{1}{K_B^*}+\frac{1}{K_d^*} \qquad (1)$$

The analysis model for the frame is expressed with one mass system shown in Figure 7. In this Figure 8, *W* is showed as mass (=8.7×10^{-5} t·sec^2/cm), *K* is showed as equivalent shear stiffness (=1.07t/cm), and *C* is expressed for structural viscous damping coefficient (*h*=0.003, *h*: damping ratio). Besides, the relationship between velocities and damping forces was expressed with planned characteristics shown in Figure 2. New Mark β method was applied for time historical analysis. A value for β was selected as 1/6. Time step interval was set up for 0.0001 seconds for the time historical response analysis with considering analytical stability.

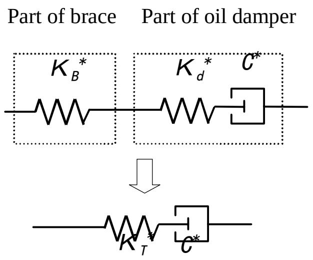


Figure 6: Analysis model for ODB-system

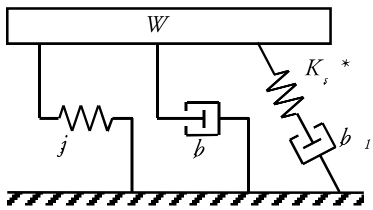


Figure 7: Analysis model for the frame with one mass system

4.1.2 Analysis results:

There is the relationship between damping forces and displacements in Figure 8, and the relationship between shear forces and displacements in the frame is showed in Figure 9. There are the results for the cases of loading values in the servo as 1.0t, 2.0t and 3.0t in the time history.

In the case of loading values in the servo as 2.0t and 3.0t, relationship between damping forces and displacements shows almost that near at 1.0t in relief loading, because damping velocities are over 0.4 cm/sec as relief velocity. On the other hand, it is possible to see ellipse on the time more than 2.0 second. We can check that both results from testing and analysis are showed good agreement with using two cycles.

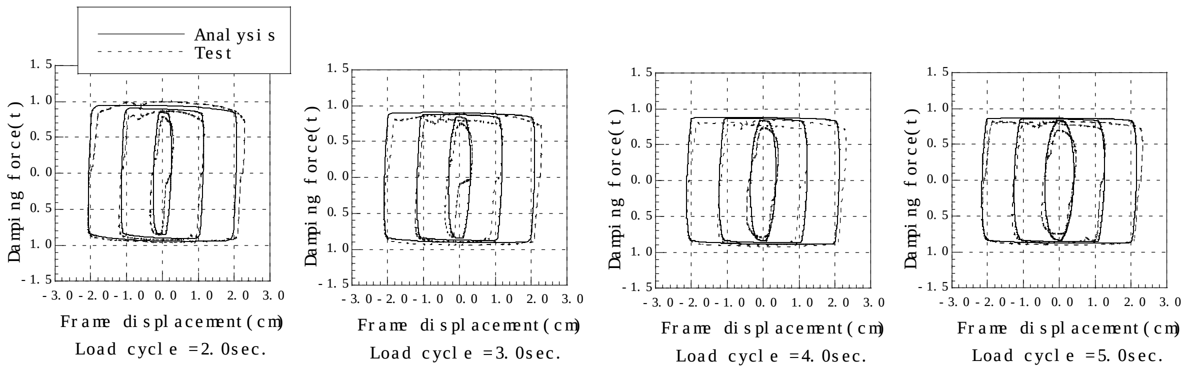


Figure 8: Relationship between damping forces and displacements

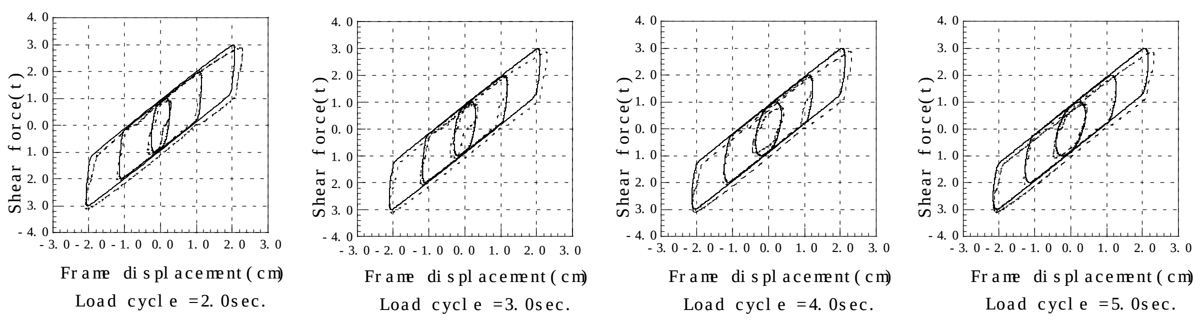


Figure 9: Relationship between shear forces and displacements

4.2 Analysis of 2-dimensional frame structure

4.2.1 Analysis model:

In the structural design with ODB-system, it must sometimes be necessary for us to consider the changes of axial forces in the columns around dampers and the changes in the effect from dampers with components of deformation by bending moments in the structure. In that case, we must analyze responses for the member levels. We developed the dynamic response analysis program for 2-dimensional from structures. This program can arrange all of oil dampers setting in the frame into the Maxwell models. The analysis method and comparison between analysis results and testing results are reported in this section. The model for Maxwell element is showed in Figure 10. This Maxwell model would be set up between two points in two panels. The relationship between damper velocity and damping force is bi-flow characteristics in the plan shown in Figure2. Damping effect of Maxwell element is considered by adding vibration equation for a term of damping force of it. Vibration equation is showed in the equation (2) as followings;

$$M\ddot{X} + C\dot{X} + KX + F = P \qquad (2)$$

F: damping force vector with Maxwell model, P: loading force vector

In this program, dynamic response analysis will be performed in the horizontal direction as one mass for each floor with idea of condensation. At that time, components of the vertical direction for the damping forces in the Maxwell elements also transfer to the damping force vectors F by using the condensation procedure. The analysis model for dynamic response analysis is showed in Figure 11. Values for input parameters are showed in Table3. Newmarkβ method (β =1/4) is used in the program. Analytical time interval is used as 0.0001 second same as the analysis with one mass model.

The analysis was carried out with other parameters as followings;

1. Loading value in servo : 3.0t
2. Loading cycle: 1.0 seconds and 4.0 seconds
3. Loading wavepattern : Sine wave

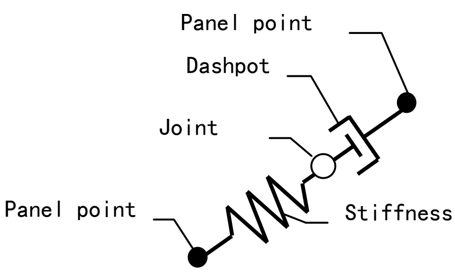


Figure 10: Maxwell element

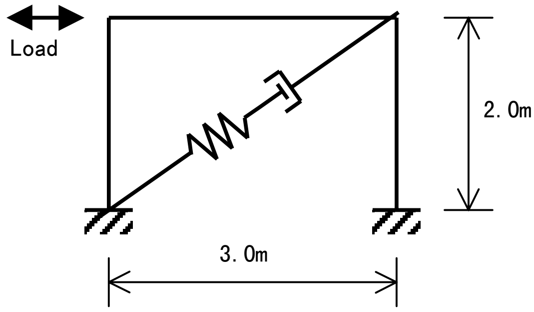


Figure 11: Analysis model

Table 4: Analysis parameter

Whole stiffness for ODB-system K_T^*	25.1(t/cm)
Primary damping coefficient C_1^*	2.5(t･sec/cm)
Secondary damping coefficient C_2^*	0.0205(t･sec/cm)
Relief load	1.0(t)
Young’s modulus of column and girder E	2100(tf/cm^2)
Column section area cA	20.9(cm^2)
Column moment of inertia cI	170.6(cm^4)
Girder moment of inertia gI	1526.7(cm^4)
Frame damping ratio	0.3(%)

4.2.2 Analysis results:

The relationship between damping forces and displacement in the damper in the loading cycle as 1.0 seconds is shown in Figure 12 and in the loading cycle as 4.0 seconds in Figure 13. Maximum displacement in the dampers from analysis is about 5% larger than testing results. Maximum damping force between analysis and testing differs 5%. Data in the time history of the axial forces in the column on the right hand side and component in the vertical direction of damping forces are showed in Figure 14 and 15 in the loading cycle as 1.0 seconds. Data in the time history for the shear forces are showed in Figure 16 and 17. Values in testing and analysis are almost in agreement.

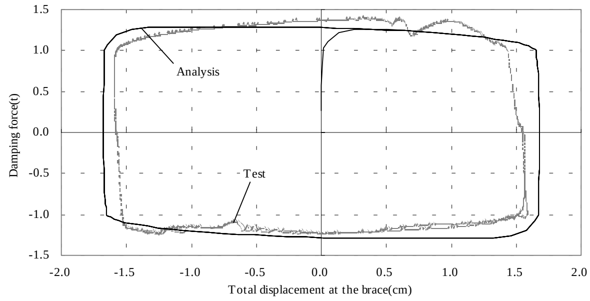


Figure 12: Relationship between damping force and Total displacement at the brace (loading cycle 1.0 seconds)

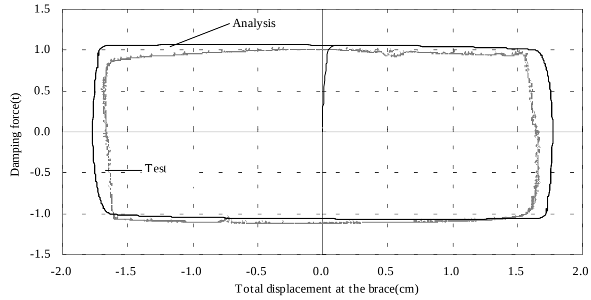


Figure 13: Relationship between damping force and Total displacement at the brace (loading cycle 4.0 seconds)

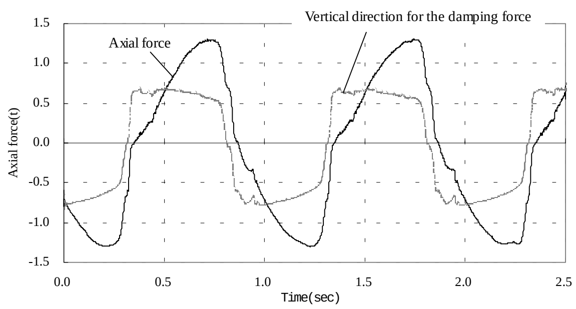


Figure 14: Time history of axial forces (Testing result)

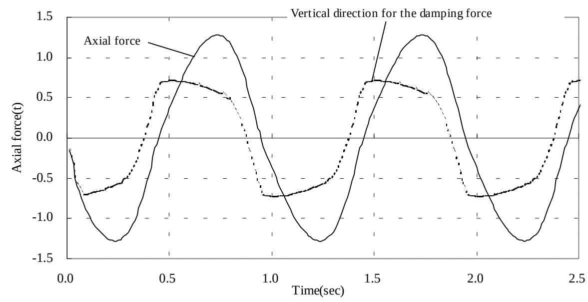


Figure 15: Time history of axial forces (Analysis result)

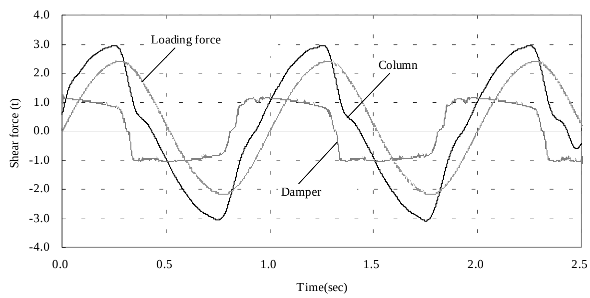


Figure 16: Time history of shear forces (Testing result)

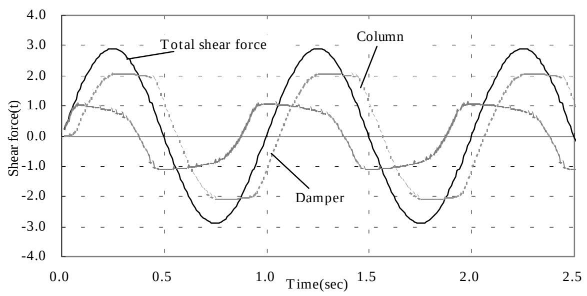


Figure 17: Time history of shear forces (Analysis result)

5. CONCLUSIONS

We reported the testing results and analysis results with the new type device ODB-system. The conclusions are summarized as followings;

1. It was confirmed that oil damper set up to the frame of ODB-system and K-shape bracing system normality cycled and effectively exhibited damping force.
2. ODB-system is inferior to K-shape bracing system in damping performance, but ODB-system does not give

the frame needless stress and exhibit damping force.

3. We carried out response analysis of one mass system with applying Maxwell model. As a result, analysis results and testing results are both well in agreement. It is verified that ODB-system can be expressed by Maxwell model and this analysis method can be applied to structural design.
4. We carried out response analysis of 2-dimensional frame structure with applying Maxwell model. As a results, analysis values and testing values of each member are both well in agreement. Therefore it is verified that this analysis method can be applied to structural design.

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