IMPACT CHARACTERISTICS ESTIMATION OF SHORT SUPPORT COLUMNS UNDER CABIN FLOOR

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Abstract

In general, open section short columns are used as compression members of aircraft fuselage under cabin. Although crippling buckling is dominant factor for determining characteristics of them, so far there are only empirical formulas for static crippling buckling. The objective of our research was to propose models for various sections of short columns based on the force-deformation relationship of compression impact and to be possible to estimate shock absorbing ability of the members for aircraft crashworthiness design. We conducted impact axial crush tests, like drop-hammer test, and quasi-static compression tests on channel section columns, lipped channel section columns, and H-section columns with aluminum A5052 isotropic material. We acquired relation curves between force and axial deformation on each column by determining impact peak buckling load empirically and using quasi-static test data for post-buckling deformation phase. We show the models are very useful for estimating shock absorbing ability of the components from the drop weight and given energy data. Moreover, we show making slit on the web of the column increased shock absorbing ability of the column members due to stable deformation mode in large post-buckling deformation.

1 Introduction

Improving crashworthiness ability of aircraft fuselage under cabin floor has been conducted with various shock absorbing components, and shock absorbing structure [1-4]. Particularly, it is very effective for helicopters and smaller transport than narrow body transport due to their small depth under floor structure [5]. Typical subfloor structure consists of floor beams, floor panels, frames, skin-stringer outer panel, and struts.

In our study, we began with channel section compression members that are often used as struts supporting the floor of aircraft fuselage [6, 7]. Figure 1 shows result after a vertical drop test of YS-11 airliner fuselage section, which was conducted on December 20th in 2001 at the former National Aerospace Laboratory [8]. In this figure, struts were kept intact forcing the bottom portion of the fuselage to fully absorb the kinetic energy by buckling and deforming largely. If the struts were more flexible, they might crash more moderately. Therefore, the whole under-floor would be more possible to crash uniformly and absorb more shock energy. It is useful that we can utilize original structural members as shock absorbers with minor modification without using special shock absorbing devices, because the members need not change design of airframe. This is the reason why we adopted the column as the beginning research object. Moreover, impact characteristics of short columns governed by crippling buckling strength with open-sections such as channel shape or H shape are not well known so far. Any of the past study of dynamic buckling columns were long columns governed by Euler buckling [9, 10], columns with given initial imperfection [11, 12], and closed-section columns or tubes with metals and composites [13-15]. Although closed-section columns are much more effective shock absorbing device than open-section columns, closed section components are not accepted by commercial transport operator owing to the corrosion problem where inspection of the inside of the closed-section is very difficult [16].

There is no proven analytical method for the prediction of the crippling stress [17], although there are some well known empirical equations for crippling buckling stress of various section types [18-20]. Thus short columns of channel section, lipped channel section, and H section with fixed ends were subjected to crush impact tests by dropping weight and quasi-static tests. And the axial impact features were thoroughly studied in order to make empirically a simplified component model of the struts for estimating shock absorbing ability and modeling force-deformation relation. The significant difference between quasi-static test results and crush impact test results in the relation of force-deformation history was initial peak load. Therefore, in the estimation model, we determined the initial buckling peak load with impact velocity of the dropping weight and equated crush impact post-buckling deformation history curve with the quasi-static deformation history curve. We showed the models were very useful for estimating shock absorbing ability of the components from the drop weight and given energy data. Moreover, we showed making slit on the web of the channel column increased shock absorbing ability of the members due to stable deformation mode in large post-buckling deformation.

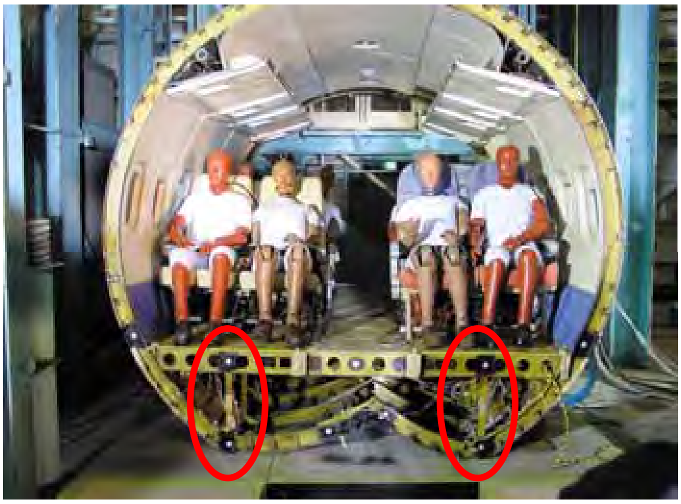
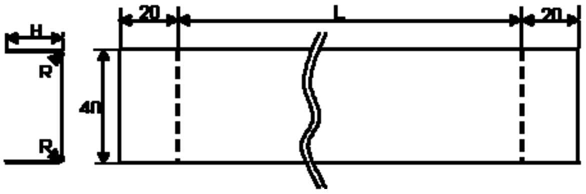


Fig. 1. Post Test Photo of YS-11 Fuselage Section Vertical Drop Test.

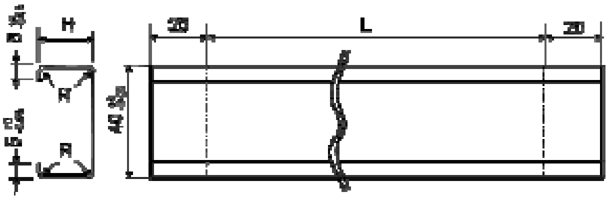
2 Experiments

2.1 Specimen

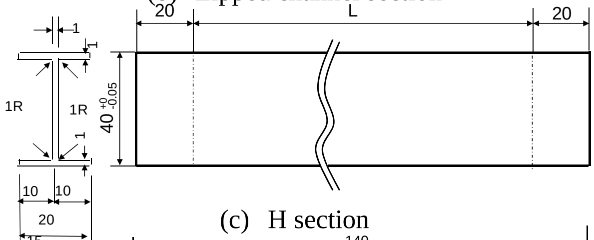
Fig. 2(a)-(e) show specimens of 100mm deformable length short column with A5052 aluminum alloy. They were the width of 40mm, the thickness of 1mm, and 15mm depth of flange of channel section specimen. And H section columns had 20mm flange. Lipped channel section had 5mm width lips. Material of the specimens was A5052 aluminum alloy because of its followable nature to large deformation without fracture unlike 7075. In Fig. 2s, *L* is the estimated specimen gauge length 100mm and 20mm ranges on both ends of the specimen were firmly fixed to jigs.



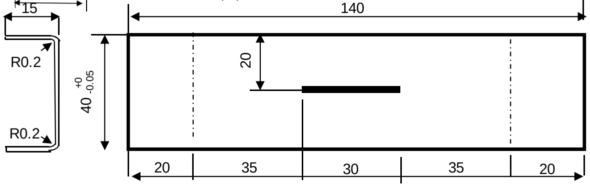
(a) Channel section



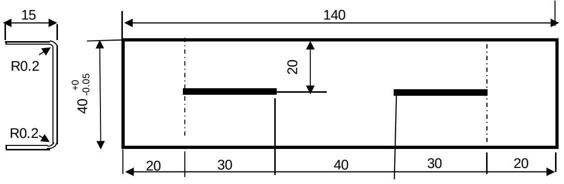
(b) Lipped channel section



(c) H section



(d) Channel section with one slit



(e) Channel section with two slit

Fig. 2. Dimensions of Test Specimen

2.2 Axial Crush Impact Test

Figure 3 shows the lower jig to fix the lower end of the channel section specimen. It has a hollow inserted the specimen between two spacers which adjust the center of the channel section to the center of the jig section. Figure 4 shows the bottom surface of the upper jig and two spacers whose width is changed with specimen width. The upper jig has the same fixed gadget with the lower one and it has a pole on the top surface of it. The pole inserts into a hole of the block on the bottom surface of the dropping weight when the dropping weight fall vertically along sliders on both sides of the drop impact test facility. This insertion into the hole fixes the upper end of the specimen. Figure 5 shows set-up of the experiment. The drop impact test facility in standard use has a weight which is able to change weight from 42.3kg to 200kg with adding steel plates on the front and back surfaces, and dropping height from 0.0m to 4.8m with setting the slider with hoisting by an electric motor. But we used a temporally additional device because the setting weights were light this time. Figure 6 shows schematic diagram of the temporally dropping device with the loading frame. And Fig. 7 shows a photograph of the device. In the case of using it, after temporally four guided poles are set, the hook for existing weight stopped function and then newly temporally light weight holder is equipped under the existing weight with a newly hook. And light weight holder slide down along the guided poles through bushes. In the test, various test conditions of weights and dropping heights of the weight were set to adjust to shock absorbing ability of each specimen. Dynamic impact loads are measured by a load cell, which is KYOWA 5tf load cell LUK-5TBS, on the bottom of the test set-up. And measurement data collected YOKOGAWA WE7000 measurement system with 10 kHz sampling rate. And pictures of crushing phenomena were taken by two high speed video cameras, Redlake MASD Inc. HG100Ks, from two different directions to record deformed motion with 10 kHz sampling rate and to calculate impact velocity and displacements of specimen shortening.

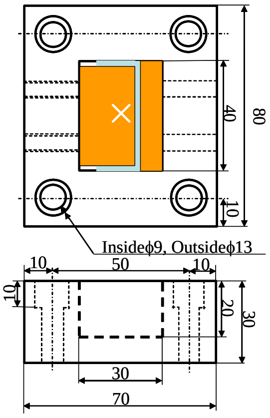


Fig. 3. Lower End Jig of the Impact Experiment Set-up

Fig. 4. Upper End Jig with Two Spacers

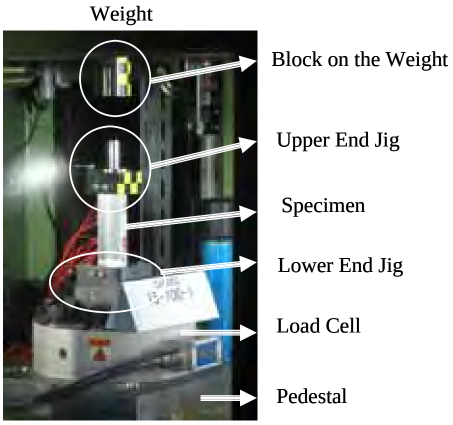


Fig. 5. Set-up of the Impact Experiment

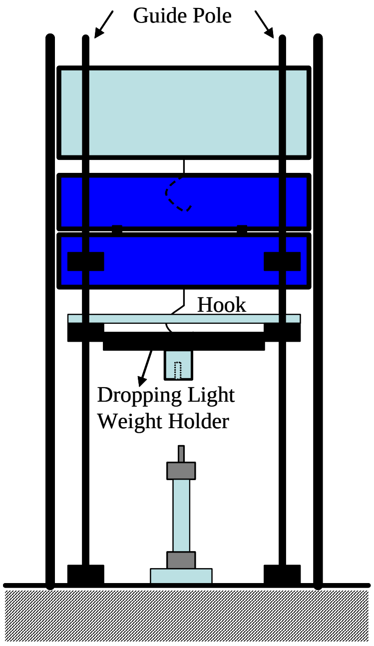


Fig. 6. Schematic Diagram of the Loading Frame with Light Weight Holder

Fig. 7. Loading Frame of the Impact Tests with Light Weight Holder

2.3 Quasi-static Axial Compression Test

We conducted quasi-static axial compression tests by using Instron 8802 (100kN) load system with using the same jigs for the axial crush impact tests. In the tests, cross head speed was 10 mm/min. Fig. 8 shows the load frame with set-up of the quasi-static test.

Fig. 8. Test Set-up of the Quasi-Static Test

3 Experimental Results

3.1 Quasi-Static Test

Fig. 9 shows results of the test with the maximum load of each specimen as crippling buckling load.

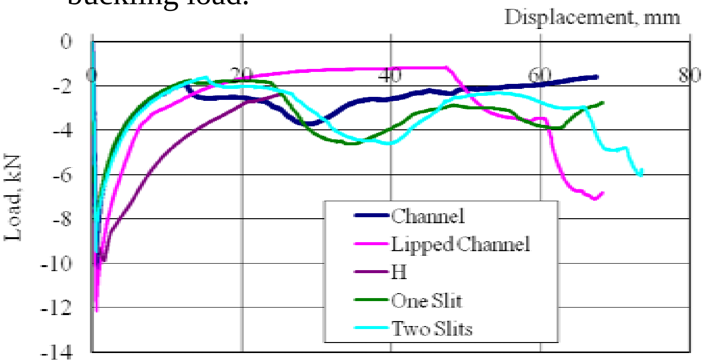


Fig. 9. Load-Displacement Relation on Each Specimen

Absorption energy of the specimens equals to the work which were consumed to deform the specimens. Therefore, energy absorption $E_w(\delta)$ at deformation δ is as following:

$$E_w(\delta) = \int_0^{\delta} |F(\delta)| d\delta \qquad (1)$$

where $F(\delta)$ is load at deformation δ. Fig. 10 shows relation between energy absorption and deformation, and Fig. 11 shows the relation deformation and energy absorption per each section area.

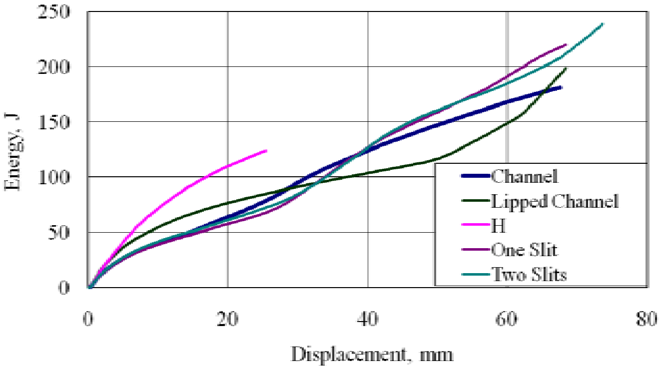


Fig. 10 Relation between energy absorption and deformation at the quasi-static test

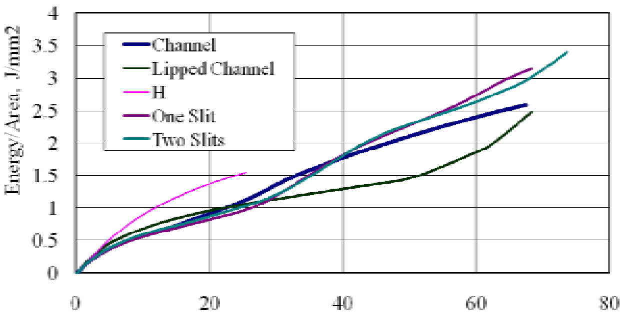


Fig. 11 Relation between energy absorption per section area and deformation at the quasi-static test

3.2 Crush Impact Test

In crash impact tests, dropping weight mass and dropping heights of the weight were changed as empirical parameters. Table 1 shows the test conditions on each specimen. In the table, C means channel section, LC is lipped channel, 1S is one slit type, and 2S is two slit type.

Table 1. Crush impact test conditions

Type	Weight, kg	Height, m
C	11.35 21.39 42.26	0.2, 0.4, 0.6, 0.8 0.1, 0.2, 0.4 0.05, 0.1, 0.2
LC	11.31 21.27 41.47	0.4, 0.8, 1.2 0.2, 0.4, 0.6 0.1, 0.2, 0.3, 0.4
H	11.35 21.39 42.26	0.8, 1.2, 1.6 0.4, 0.6, 0.8 0.2, 0.3, 0.4
1S	21.27	0.1,0.2,0,3,0.4,0.5,0.6,0.8,1.0
2S	21.27	0.1,0.2,0,3,0.4,0.5,0.6,0.8,1.0

Fig. 12 shows load, velocity and shortening deformation time history curves in case of channel type with 21.39kg weight dropped from 0.20m height with 1.59m/s impact velocity. In Fig.12, duration time defined as the time reducing from dropping weight impact velocity to zero velocity. At the time of zero velocity, deformation of the specimen was the maximum deformation δ_{max}. At the time, the specimen had the maximum energy E_T. And we acquired the relation in the weight kinetic energy, E_k, and the weight potential energy , E_p, by the specimen deformation.

$$E_T = E_k + E_p \qquad (2)$$

$$= \frac{1}{2}MV^2 + (M+m)g\delta_{\max} \qquad (3)$$

Where V means impact velocity of the dropping weight, m means mass of the upper jig, and g is the acceleration due to gravity. And we can also use Eq. (1) with crush impact case. Therefore, we can get the following equation:

$$E_{w\max} = E_w(\delta_{\max}) = \int_0^{\delta_{\max}} |F(\delta)| d\delta \qquad (4)$$

Fig. 13 showed relation between the maximum shortening axial deformation and the maximum energy absorption by each specimen. And Fig. 14 shows the relation the maximum shortening axial deformation and the maximum energy absorption per each section area.

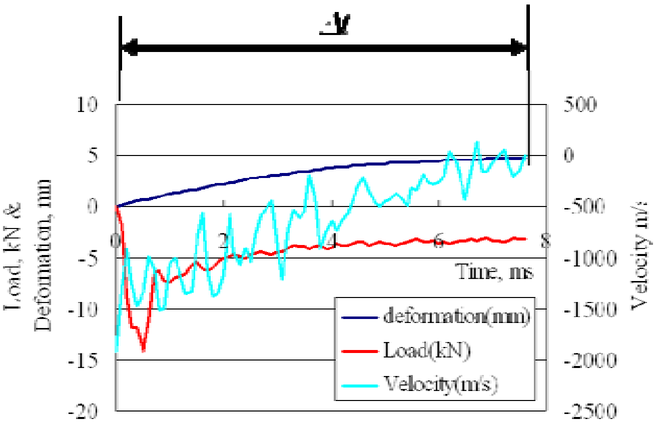


Fig. 12 load, velocity and shortening deformation time history curves in case of channel type with 21.39kg weight dropped from 0.20m height.

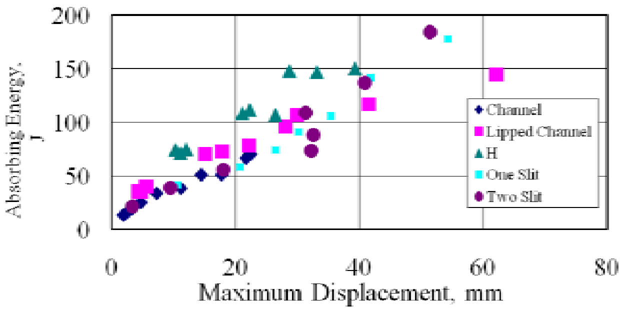


Fig. 13 Relation between the maximum energy absorption and the maximum deformation at the crush impact test

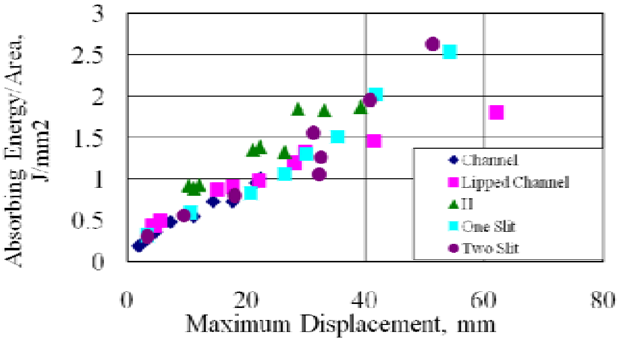


Fig. 14 Relation between the max energy absorption per section area and the max deformation at the impact test

4 Estimation Method

We propose an estimation method for shortening maximum deformation of short column in case that we get information of weight mass and weight impact velocity. This estimation will be useful with design of crashworthy structure under cabin because it shows the limit of the shortening deformation and absorbing energy for struts without full-scale drop tests. Fig. 15 shows the relation between load and shortening deformation in case of channel type specimen with crush impact test and quasi-static test. It is clear that the significant difference between impact test and quasi-static test is initial peak load, crippling buckling load. And the faster the impact velocity is, the larger the peak load is. We estimate the peak load empirically by using Cowper-Symonds equation of strain rate relation as a hint [11, 21]. That is, dynamic buckling load F_{db} is estimated from quasi-static buckling load F_{sb} by using the following equation,

$$\frac{F_{db}}{F_{sb}} = 1 + \left(\frac{\dot{\varepsilon}}{\alpha}\right)^{\beta} \tag{5}$$

$$\dot{\varepsilon} = \frac{\Delta d}{l} \bullet \frac{1}{\Delta t} = \frac{\Delta d}{l} \bullet \frac{V}{\Delta d} = \frac{V}{l} \tag{6}$$

where l is column length, and α and β are constants which are inherent in each section type. These constants are determined empirically by interpolation and logarithm on both sides of Eq. (5). Table 2 shows pairs of α and β on each type section of the short columns. Fig. 16 shows estimated peak loads and the corresponding empirical peak load.

Table 2 Pairs of α and β in Eq. (5) on each section

	α	β
Channel	36.7	0.9366
Lipped channel	34.4	1.18
H	38.9	0.58

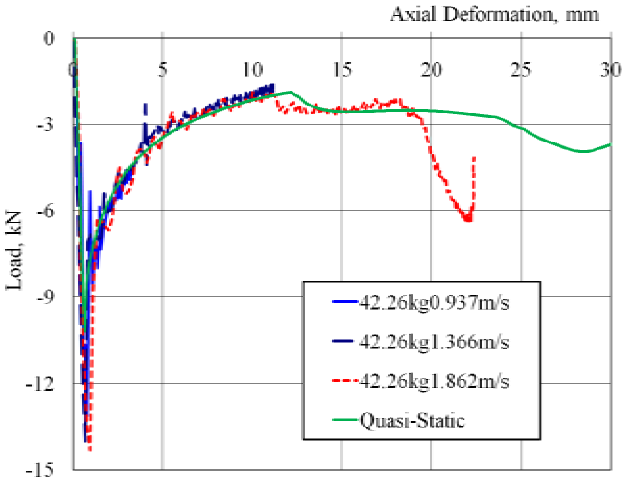


Fig. 15 Example of relation between shortening deformation and load of impact test and quasi-static test

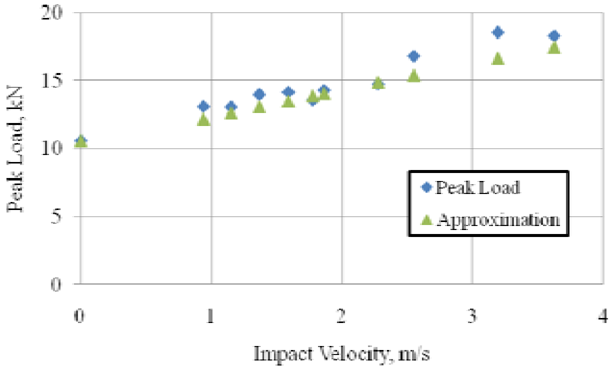


Fig. 16 Example of empirical estimation results of dynamic buckling peak load of channel column

At the maximum shortening deformation state, we can acquire the following equation with ignoring energy loss.

$$E_T = E_{w\max} \tag{7}$$

$$\frac{1}{2}MV^2 + (M+m)g\delta_{\max} = \int_0^{\delta_{\max}} \left|F(\delta)\right| d\delta \equiv G(\delta_{\max}) \tag{8}$$

$$\frac{1}{2}MV^2 = G(\delta_{\max}) - (M+m)g\delta_{\max} \tag{9}$$

If we can determine $G(\delta)$ function, We can calculate backward to estimate the maximum

shortening deformation in corresponding to given weight and impact velocity.
We propose two models:
Model 1: Quasi-static load deformation curve,
Model 2: Initial peak load is estimated by Eq. (5) and the deformation at the peak load is the same as the quasi-static deformation. The peak load value, zero deformation load value and quasi-static load value with 1mm deformation are connected like a triangle. And beyond 1mm deformation part, the model is the same curve as the quasi-static curve.

Fig. 17 shows estimation results with channel section case. The horizontal axis is the drop weight kinetic energy and the vertical axis is the maximum shortening deformation. This shows that Model 2 proposes better estimation than Model 1.

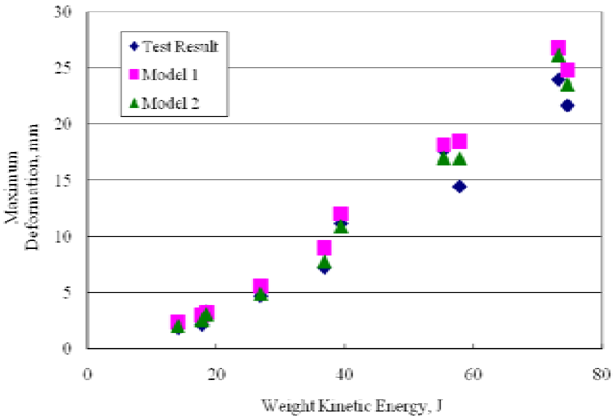


Fig.17 Example of result of the estimation method

5 Discussion

From Fig. 11 and Fig.14, lipped channel, channel and channel with slip are equivalent ability to shock absorbing per section. H section has better shock absorbing ability. Because H section needs larger load in deformation than the others. Therefore, H section is hard to deform, so we have to handle it carefully in design. Channel section with slit column is easy to deform. Stable post-buckling mode occurs and it can use effectively large part of the specimen. It is very useful as shock absorbing device with conventional component under floor cabin.

The estimation method shows that it will be possible to impact characteristic from the quasi-static test without impact test.

6 Concluding Remarks

We determined the initial buckling peak load with impact velocity of the dropping weight and equated crush impact post-buckling deformation history curve with the quasi-static deformation history curve. We showed the models were very useful for estimating shock absorbing ability of the components from the drop weight and given energy data. Moreover, we showed making slit on the web of the channel column increased shock absorbing ability of the members due to stable deformation mode in large post-buckling deformation. In near future, we simplified model based on the above force-deformation relationship is used to analyze the compression impact behavior of the support column under cabin floor, by incorporating the model into the explicit transient finite element code LS-DYNA.

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