SMiRT-12 / K. Kussmaul (Editor)
1993 Elsevier Science Publishers B.V.

JH13/6

FIELD TEST ON SHOCK-ABSORBING EFFECT OF THREE-LAYERED ABSORBING SYSTEM

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ABSTRACT

In this paper, the experimental study on absorbing capacity of three-layered absorbing system is discussed. This system is composed of 50 cm thick sand layer (top), 20 cm thick core RC slab reinforced with braided AFRP (Aramid Fiber Reinforced Plastic) rods and 50 cm thick EPS (Expanded Poly-Styrol) (bottom). The experiments are performed by free falling of a 3 tonf weight on to the absorbing system from 30 m high.

It is described that the proposed absorbing system is superior to a single sand layer with 90 cm high in terms of all absorbing functions considered here.

1. INTRODUCTION

To ensure the greater safety of facilities of nuclear power plants, fuel tanks, rock-sheds or other important structures against impact loads, many theoretical and experimental studies have been reported. A great deal of effort has been made on the investigation of impact behavior and impact-resistance of structures when flight and/or falling bodies applied on the structure directly. Authors have worked on the dynamic behaviors of RC and PC members under impact loading[1,2]. The applicabilities of RC and PC members using braided AFRP(Aramid Fiber Reinforced Plastic) rods as reinforcing bar and PC tendon to the part of impact-resistance structures were also considered[3,4,5]. As a result, it is clear that those members can be used as impact-resistant structures likewise to the customary RC and PC members.

Otherwise, it will be one of engineering approaches to attenuate the impact forces at the quasi-static level by using absorbing system. It is for this reason that the structures is designed by customary design method if the applied loads on the structure were quasi-static level such that the intensity is low and the time duration is longer than half of the first fundamental natural period of structure.

AFRP rods are excellent in resisting corrosion and non-magnetic in behavior, and having light weight, high strength and wide elastic strain zone compared with a steel bar. Impact forces may be effectively attenuated by using the absorbing system utilizing the special features of AFRP rods.

In this paper, the absorbing capacity of three-layered absorbing system are experimentally considered. This absorbing system is composed of 50 cm high sand layer (top), 20 cm high RC slab (core) and 50 cm high EPS (Expanded Poly-Styrol) layer (bottom), in which RC slab is reinforced with AFRP rods. In order to study the effects of rigidity, elongation and bond strength of a reinforcing bar in the core RC slab on the shock absorbing performance of the absorbing system, three types of reinforcing bar were used; AFRP rods with/without silica sands and deformed steel bars. Furthermore, these results were compared with the results in case using a single sand layer as absorbing system[6] and theoretical results obtained from Hertz's contact theory[7].

The impact loads were generated by free falling of a 3 tonf weight on the center of the absorbing system from 30 m high.

2. OUTLINE OF EXPERIMENT

2.1. Method of experiment

Figure 1 illustrates the profile and dimensions of the absorbing system used for the experiments. A three-layered absorbing system was mounted on RC foundation with the dimensions of 660 × 660 × 60 (cm). The absorbing system was subjected to impact loads by free falling of a 3 tonf cylindrical weight covered with steel shell having a flattened spherical bottom (diameter of cylinder is 100 cm, height of cylinder is 97 cm and height of spherical bottom is 17.5 cm) from a predetermined height.

The experimental cases are listed in Table 1. In these experiments, six numbers of absorbing systems were made and tested, a impact load was applied on the center of each absorbing system.

2.2. Core slab

Material properties of reinforcing bar used in these experiments are listed in Table 2. RA- type is braided AFRP rods which are manufactured by saturating them with resin after the aramid fibers were braided. RA9S, RA13S and RA15S are bonded with no. 5 silica sand on the surface of each type of AFRP rods. These AFRP rods have many advantages compared to the conventional steel reinforcement bars such as lightweight, nonmagnetizable and corrosion resistance. As shown in Table 2, the elastic elongation of a AFRP rod is about 10 times than that of steel bar and elastic modulus is about one third of steel bar.

Each slab of absorbing systems is doubly reinforced. The mix proportion of the concrete was designed to produce a design strength of 210 kgf/cm^2. On commencement of the experiment, compressive strength and elastic modulus of concrete are 188 ~ 218 (kgf/cm^2) and 2.67 ~ 2.79 (× 10^5 kgf/cm^2) respectively.

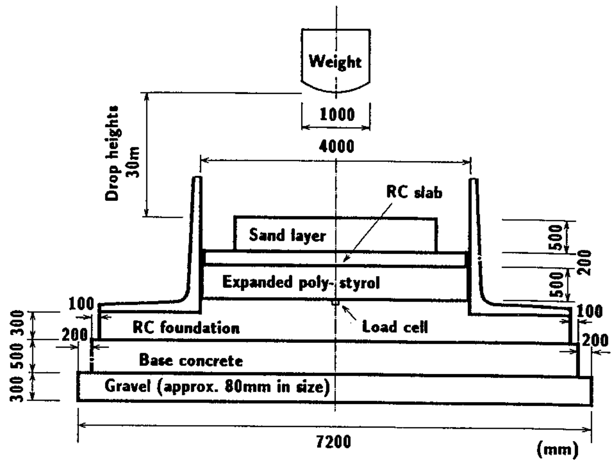

Fig. 1. Profile and dimensions of the absorbing system

Table 1. Experimental cases

Nominal name	Reinforcing bar of core slab	Thickness of slab	Reinforcement ratio (%)
As-20-1.0	Sand-surfaced rod (RA13S)	20	1.0
A-20-1.0	Non-sand surfaced rod (RA13)	20	1.0
As-20-0.5	Sand-surfaced rod (RA9S)	20	0.5
As-30-1.0	Sand-surfaced rod (RA15S)	30	0.5
D-20-1.0	Deformed steel bar (D13)	20	1.0
S-90	A single sand layer with 90 cm thick		

Drop height is 30 m and reinforcement is double.

Table 2. Material properties of reinforcement

Nominal name	RA13 RA13S	RA9S	RA15S	D13
Material	Aramid	Aramid	Aramid	SD295A
Nominal diameter (mm)	12.7	9.0	14.7	12.7
Nominal sectional area (mm^2)	127	63	170	127
Tensile strength (tf)	19.2	9.6	25.6	5.7 ~7.7
Yield strength (ft)	-	-	-	3.8 or more
Elastic modulus $\times 10^6$ kg/cm^2	0.7	0.7	0.7	2.1
Elastic elongation (%)	2.0	2.0	2.0	0.2

Table 3. Material properties of sand.

Unit weight (tf/m^3)	Specific gravity	Moisture percentage (%)	Uniformity coefficient
1.6	2.59	5.3	5.72

2.3. Material of top and bottom layers

Table 4. Material properties of EPS.

Density (kg/m³)	Strength at 5% strain (kgf/cm²)	Poisson's ratio	Max. of elastic strain (%)	Stress at the max. elastic strain (kgf/cm²)
20	1.2	0.05	1 or less	About 0.6

In these experiments, sand layer and EPS layer with 50cm thickness in each were used as top and bottom layer respectively. The material properties of sand are indicated in Table 3. Sand was spread and compacted in each 20 cm layer with stamping.

The material properties of EPS used as bottom layer are indicated in Table 4. In these experiments, blocks of EPS with dimensions of 200 × 100 × 50 (cm) were arranged to form the predetermined size of 400×400×50 (cm).

2.4. Measuring method

The acceleration of the free-fallen weight was measured by using 4 accelerometers to calculate the impact force generated when the weight collided with absorbing system.

The impact loads transmitted to the RC foundation were measured in one direction using 39 load cells located along the center line of RC foundation. Diameter and capacity of each load cell were designed as 32 mm and 100 kgf/cm^2 respectively. In these experiments, as it was a main objective to obtain the transmitted stresses, the transmitted impact loads measured by load cells were converted into the stresses.

Outputs from the individual sensors were recorded by wide-band data recorders, then A/D conversion was made and the data were finally processed using workstations.

3. EXPERIMENTAL RESULTS AND CONSIDERATIONS

3.1. Wave configuration of transmitted impact stress

The wave configurations of the transmitted impact stresses measured by load cells are shown in Fig. 2. In this figure, horizontal and vertical axes in the plane of paper indicate the location of load cell (cm) and transmitted impact stress (kgf/cm^2) respectively, and the axis of time (msec) is taken in deep direction. The origin of the figure is the center of loading which is at the center of RC foundation. The wave patterns on two sides of the center of loading were almost symmetric to each other. Hence, this figure shows that the wave at load cell located only on one side of the center of loading between the center and the edge of RC foundation. The total sampling times in all cases are 200 msec.

The wave configurations of As-20-1.0 and D-20-1.0 are almost the same to each other and show a good stress dispersibility. Based on the fact that the elastic modulus of a AFRP rod is one third of a steel bar, these results implies that the stiffness of reinforcing bar may not affect the distribution of transmitted

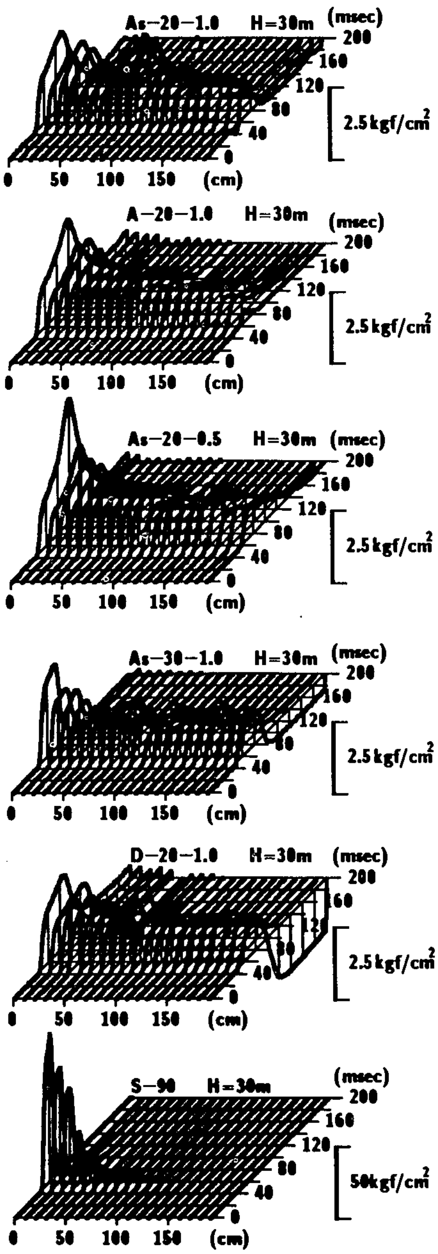

Fig. 2. Wave configuration of transmitted impact stress

impact stress.

Comparing with the results between As-20-1.0 and A-20-1.0, the stresses near the loading point of A- type are greater than those of As- type and the stress dispersibility of A- type is inferior to that of As- type. This means that the bonding property of reinforcing bar affects the stress concentration of transmitted impact force near the loading point.

Comparing with the results between As-20-1.0 and As-20-0.5, the stress distribution in case of As-20-0.5 shows a severe stress concentration near the loading point. It is clear from this comparison that the reinforcement ratio severely affect the dispersibility of transmitted impact stress.

In case of As-30-1.0, stress distribution is flatten out a little and time duration is shortened comparing with the result of As-20-1.0. This implies that the stiffness of core slab affects the dispersibility and time duration of transmitted impact stress.

Furthermore, comparing with the distribution of transmitted impact stress between three-layered absorbing system and a single sand layer, the former displays lower stress level, excellent stress dispersibility and lengthened time duration in contrast to the later ones. From these results, it is obvious that, three-layered absorbing system will be superior to a single sand layer in terms of absorbing capacity.

3.2. Wave configurations of impact forces

In this paper, the following two methods were used for the evaluation of impact force generated when the weight dropped on the absorbing system; (1) impact force obtained by multiplying the acceleration of the weight by its mass (here- after referred to as the weight impact force) and (2) impact force obtained by summing up the distributed stresses measured by the load cells (hereafter referred to as the transmitted impact force). Assuming that two transmitted impact stresses from the origin are the same in both directions, the transmitted impact force was calculated by integrating the measured stresses on one side of the origin.

Figure 3 shows the wave configurations of weight and transmitted impact forces with respect to time by solid and broken lines respectively. From this figure, the wave configurations of three-layered absorbing systems are almost the same in all cases. In these wave configurations, the waves of weight impact force are composed of two components, the first one is half sine wave having high amplitude and about 20 msec of half period, and the second one is, having amplitude less than a half of the first component and 60~80 msec of half period. Therefore, the maximum impact force is caused at the beginning of impact which may be generated by indirect collision between dropping weight and core RC slab. However, this component does not appear in the transmitted impact stress and/or force as shown in Fig. 2 and/or broken lines of Fig. 3. The main reason will be that the core RC slab makes the concentrated weight impact force near the loading point spread out and EPS of the bottom layer absorbs them.

The wave distributions of the transmitted impact forces are similar to the second component of weight impact force mentioned above. Then, the maximum transmitted impact force may be less than a half of the maximum weight impact force.

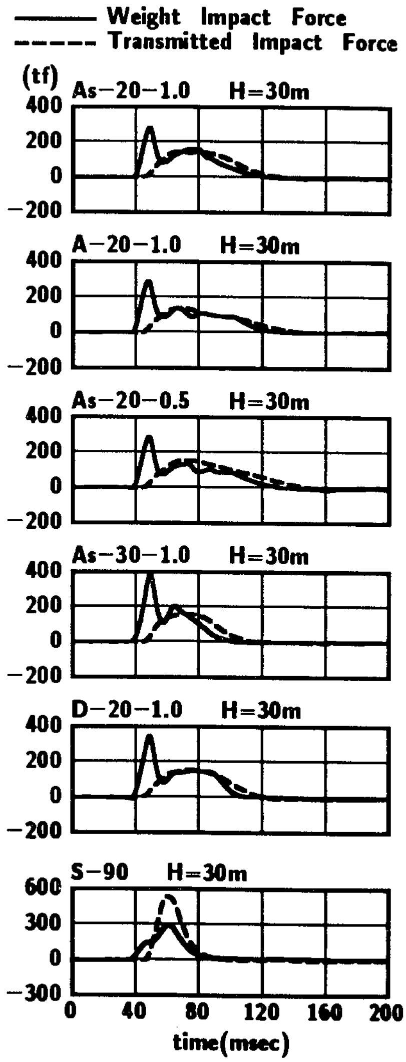

Fig. 3 Wave configurations of impact forces

On the other hand, the waves of impact forces for a single sand layer(S-90) are listed up the following characteristics from the figure; 1) the configurations of both waves are almost monotonic half sine ones, 2) time duration of the main waves is about 40 msec which is less than that of three-layered absorbing system, 3) the maximum transmitted impact force is greater than 1.6 times that of weight impact force, contrasting to the result of three-layered absorbing system. Then it is clear that the three-layered absorbing system is superior to a single sand layer in terms of all absorbing functions.

3.3. Maximum impact forces

Figure 4 shows both of the maximum impact forces for each absorbing system comparing with the results obtained from Hertz's contact theory[7]. The impact force P formulated on the basis of the Hertz's contact theory is shown as

$$P = 2.455\,\lambda^{2/5}\,W^{2/3}\,H^{3/5} \qquad (1)$$

in which λ : Lame's constant (tf/m^2), W : weight of a falling weight (tf) and H : falling height of weight (m).

From these results, even though the maximum weight impact forces of As-30-1.0 and D-20-1.0, which have a bigger stiffness of core RC slab than the others, are bigger than those of other three-layer absorbing systems, the maximum transmitted impact forces of all three-layered absorbing systems show similarity and they are less than the theoretical value in case of λ = 40 tf/m^2.

On the other hand, the maximum transmitted impact force of S-90 nearly equals to the theoretical value in case of λ = 800 tf/m^2. Therefore, the transmitted impact forces in case using three-layered absorbing systems are less than one fourth of that in case using a single sand layer(S-90).

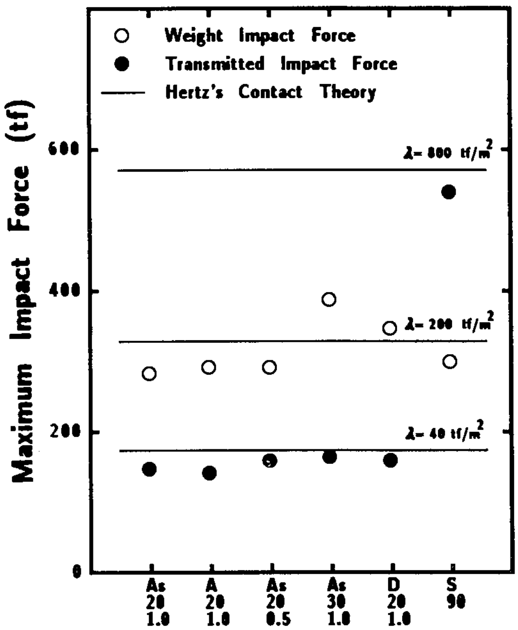

Fig. 3. Comparison of the maximum impact forces

3.4. Time duration of impact forces

Time durations for both impact forces are plotted in Fig. 5. Hence, only the case of transmitted impact force is considered. In case of three-layered absorbing system, the cases of core RC slab having a bigger stiffness (As-30-1.0 and D-20-1.0), shorter time duration and the other have longer time duration than 100 msec. The case of As-20-1.0 shows the longest time duration in all cases. Then, in order to lengthen the time duration of transmitted impact force, it should be better to use the core RC slab which has thinner thickness and reinforced with the bar having excellent bonding capacity.

Time duration in case of S-90 is less than 50 msec which is less than one half of three-layered absorbing system. Considering that the fundamental natural period of real RC shed structure may be less than 100 msec and half of the

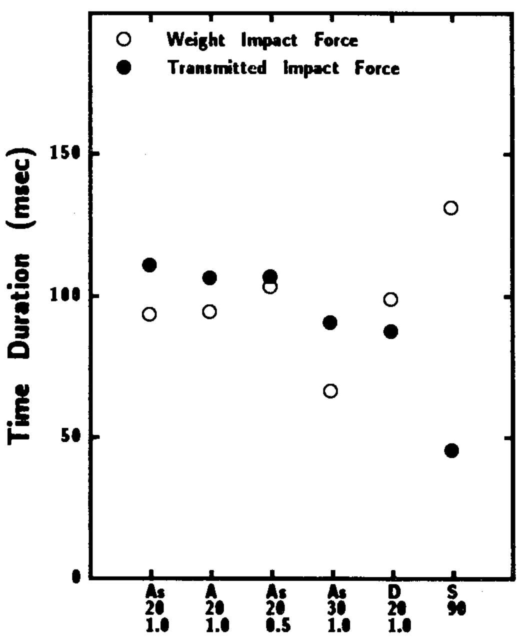

Fig. 4. Comparison of time duration of impact forces

fundamental vibration of structure is closer to the time duration of transmitted impact force, the dynamic response of structure must be severely affected by using a single sand layer(S-90).

4. CONCLUSIONS

The field test on absorbing capacity of three-layered absorbing system were performed which is composed of 50 cm thick sand layer (top), 20 cm thick core RC slab reinforced with braided AFRP rods and 50 cm thick EPS (bottom). Affections of stiffness and bonding capacity of reinforcing bar, reinforcement ratio and stiffness of core RC slab to absorbing capacity are considered. Absorbing capacity of the proposed absorbing system is also compared with the results in case using core RC slab reinforced with steel bar and a single sand layer.

The results obtained in this study are summarized as follows;

1) The wave configuration of transmitted impact stress is affected by the stiffness of core RC slab, reinforcement ratio and bonding capacity of reinforcing bar.
2) The maximum transmitted impact force in case using three-layered absorbing system is not affected by all of core RC slabs considered here, but its time duration is affected by the stiffness of core RC slab and bonding capacity of reinforcing bar.
3) Based on the maximum transmitted impact force obtained from this three-layered absorbing system proposed here has 4 times absorbing capacity of a single sand layer.

ACKNOWLEDGEMENTS

We would like to thank Dr. Sumio G. Nomachi (prof. of Nihon University) for helpful suggestions and comments in executing this project. Mr. Yasushi Oyama (graduate student of Muroran Institute of Technology) helped us in processing experimental test data.

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