Innovative Application of Combined Steel and Polyurethane Structures

Nouvelle application de structures hybrides acier-polyuréthane

Neuer Anwendungsbereich für Verbundkonstruktionen aus Stahl und Polyurethan

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SUMMARY
It is effective to use a composite structure with the shell made of steel plates and rigid polyurethane foam as a buffer of a protection device to absorb the energy forces. This paper describes experiments in which impact forces were exerted on the composite structure buffer models, with the characteristics of rigid polyurethane foam, and the application of the composite structure buffer to various protection devices.

RESUME
L'utilisation d'une structure hybride composée d'une paroi de tôles d'acier et d'une mousse de polyuréthane rigide est efficace en tant que dispositif de protection absorbant l'énergie due aux forces d'impacts. L'article décrit les expériences au cours desquelles des forces d'impacts ont été exercées sur les modèles tampons de structures mixtes, les caractéristiques de la mousse de polyuréthane rigide, et les applications de structures mixtes pour divers dispositifs de protection.

ZUSAMMENFASSUNG
Für die Ausbildung einer Schutzvorrichtung für Stossbelastungen ist eine Verbundkonstruktion aus Stahlblech und Polyurethan-Hartschaum, der die Energie des Stosses absorbiert, wirkungsvoll. Es werden Versuche beschrieben, bei denen solche Verbundstrukturen Stossbelastungen ausgesetzt wurden. Die Charakteristiken des Polyurethan-Hartschaumes sowie der Anwendungsbereich solcher Puffer-Elemente wird aufgezeigt.

1. INTRODUCTION

When used as a buffer of a protection device, the composite structure composed of the shell steel and rigid polyurethane foam absorbs the energy of the impact forces acting on the structure because the characteristics of each material are combined and supplement each other. This paper describes the experiments in which a bow model, an example of colliding bodies, collapses with and penetrates into the several buffer models made of grid type steel shells in which rigid polyurethane foam is filled. It is considered that the results of the experiments show a typical behavior which appears when impact forces are exerted on this type of composite structures. As the characteristics of this behavior became clear through the experiments, the practical use of the composite structure buffer as various protection devices is expected.

This paper describes the experiments using composite structure buffer models, the characteristics of rigid polyurethane foam, and the application of the composite structure buffer to protection devices.

2. TESTS ON ENERGY ABSORBING CAPACITY OF BUFFER EQUIPMENT

To investigate the effectivity of the buffers, model tests were done by providing a situation that bow models as shown in Fig. 1 collide with and penetrate into several types of buffers. Prior to the model tests, experiments to investigate the energy absorption process of buffers themselves were made using the rigid bodies (rigid bows) with the same shape as that of the bow models used for the model tests.

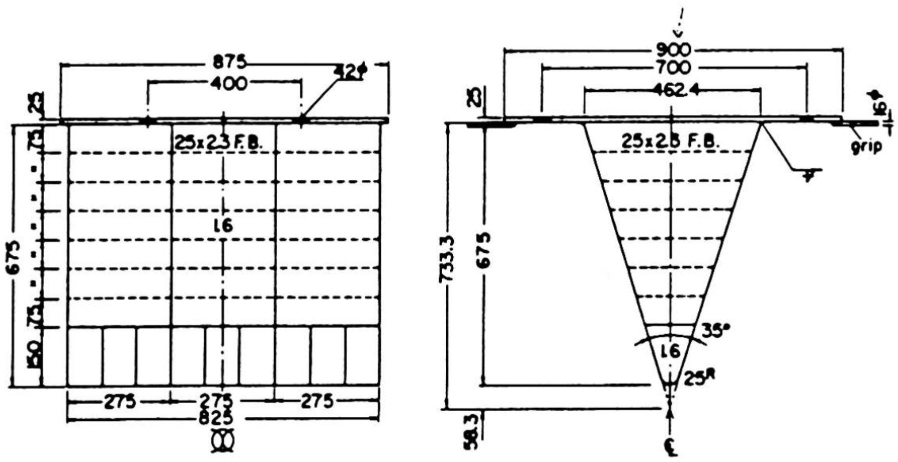


Fig. 1 Bow model

The buffer models used for the experiments were of four types: two grid type models made of girder plates, one with a large panel between girders called to be the grid (coarse) type and the other with a short panel called to be the grid (dense) model; a grid-composite type that rigid polyurethane foam was filled as a homogeneous material into the grid type model; and a composite type that rigid polyurethane foam was filled into a shell made of steel plates. Fig. 2 shows the dimensions of the grid (coarse) type model and the composite type model as typical examples of the models. A span of the grid (coarse) type model was divided into five panels and each panel was divided into two sections in the bow penetration direction (vertical direction). The rigid polyurethane foam used for the composite type models has a force-penetration characteristic of the constant compressive strength against deformation. (Fig. 5.) Figs. 3 and 4 shows the force-penetration curves of the buffer models and the absorbed energy-penetration curves obtained by integrating penetration. There are two peaks on each force-penetration curve of both coarse and dense grid type models.

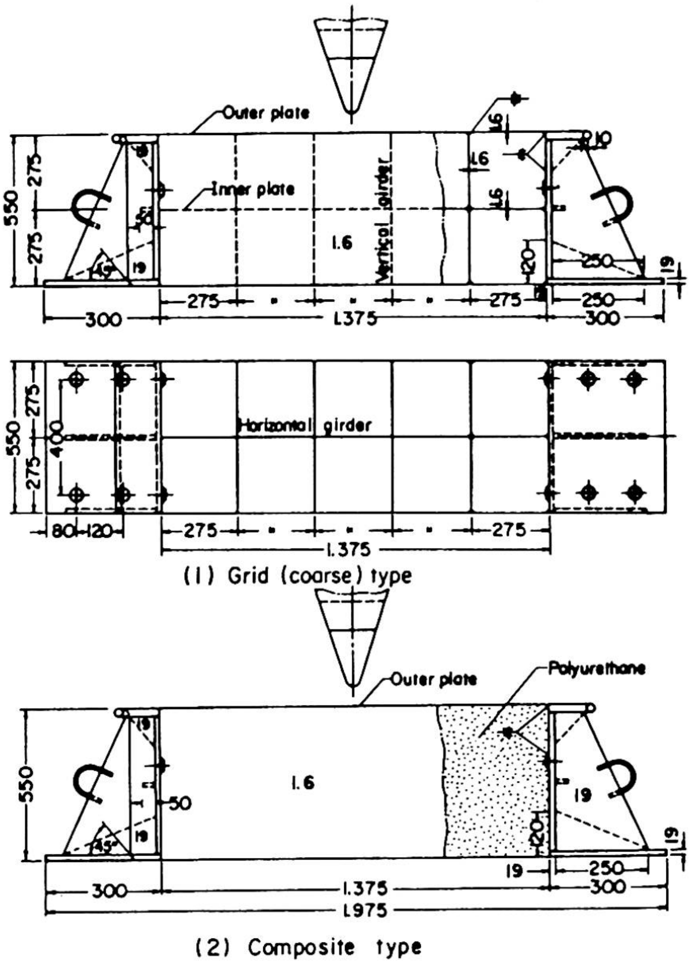


Fig. 2 Buffer models

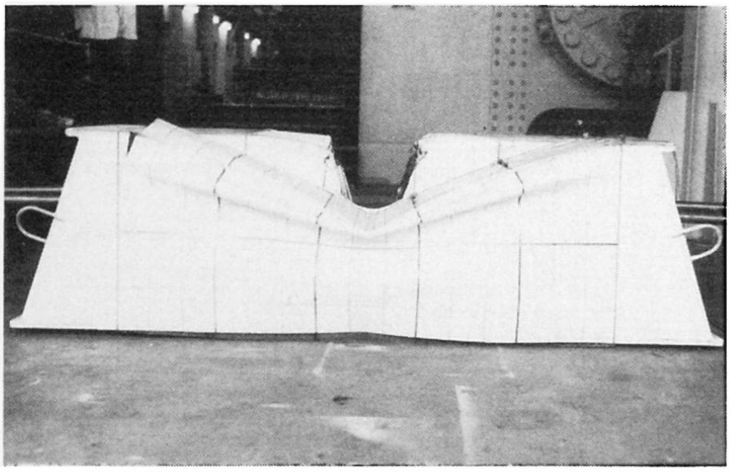


Photo 1 Buffer models

The first and second peaks were mainly due to the tension of the outer plates and that of the inner plates, respectively. When these plates fracture, forces were decreased and the outer plates of the bow came into collision with the vertical girders of the buffer models. The outer plates of the bow were damaged. The peak of the force-penetration curves of the grid-composite type model filled with rigid polyurethane foam was relatively moderate: the damage of the outer plates of the bow by the vertical girders of the buffer model was small. This means that rigid polyurethane foam filled in the grid-composite type model improved the force-penetration characteristic. The force-penetration curve of the composite type model showed that deformation spread along the transverse direction and forces were gradually increased. In Photo 1, the deformation conditions of the grid type buffer models and the composite type buffer model are compared. As is obvious from Fig. 4, the amount of the energy absorbed by the buffer models differed with the penetration of a bow into the buffer models. The fact that the absorbed energy-penetration curve of the composite type differed from those for the others denotes that the thicker the buffer thickness, the more energy the composite type model absorbs.

The results of the other model tests using bow models (not rigid) showed a similar tendency to those obtained by the experiments using rigid bows except that only bow models themselves were collapsed when forces exceeded the collapse strength of the bow models. In this point, it can be said that a buffer of which the forces are gradually increased while a bow is penetrating into it is most appropriate to cope with a wide range of bow strengths.

3. CHARACTERISTICS OF RIGID POLYURETHANE FOAM

It is to be desired that the energy absorption material against the

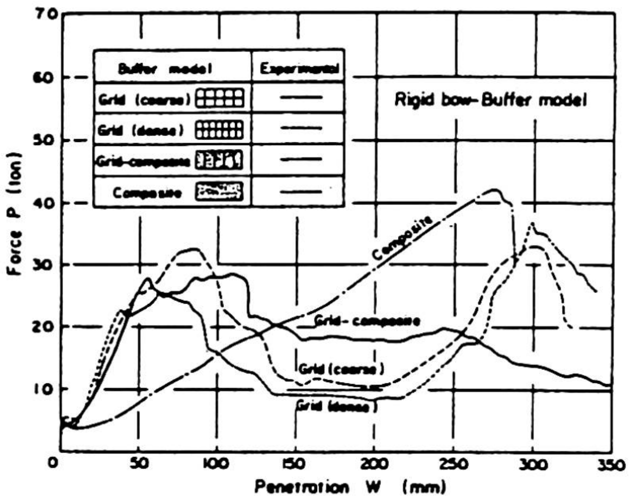


Fig. 3 Force-penetration curves of several kinds of buffer models

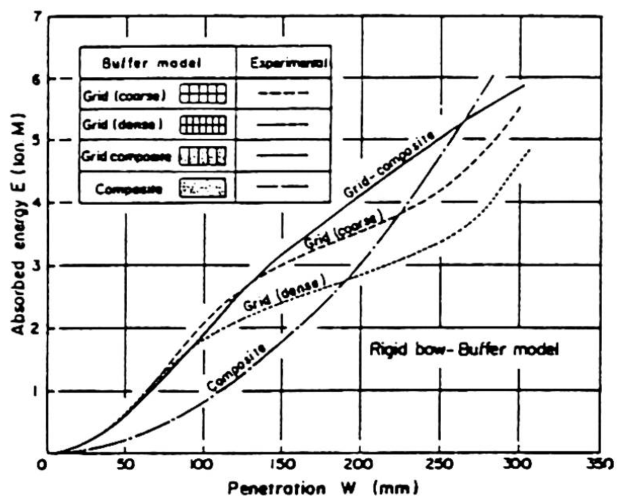


Fig. 4 Absorbed energy-penetration curves of several kinds of buffer models

impact forces maintains the constant force and also has the large deformation, namely it has the high efficiency of buffer action.

The rigid polyurethane foam mentioned in this paper varies from ordinary polyurethane foam in behavior of collapse. It was newly developed for the energy absorption material and manufactured to keep the mean value of diameter of the small cells more than 0.6mm so that these cells could collapse continuously and brittly due to the compression.

The experimental results of the static and dynamic compression test are shown eachly in Fig. 5. and Fig. 6. Table 1 shows the comparison between the rigid polyurethane foam and other materials. It is obvious that the rigid polyurethane foam is superior to the others in efficiency of buffer action.

The rigid polyurethane foam has some other features as follows.

(1) It is light in weight. (2) It has the large adiabatic effect. (3) It consists of many closed cells and the change of buoyancy in water is small.

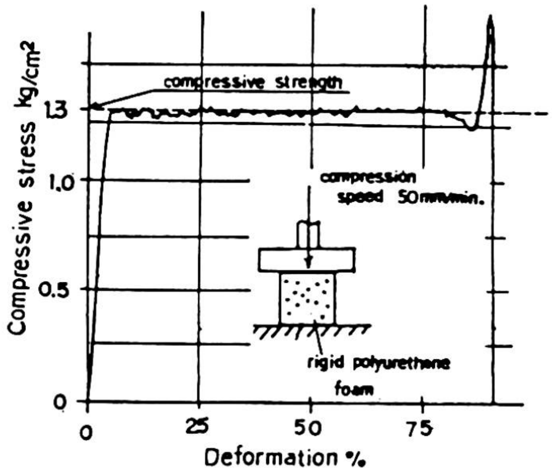


Fig. 5 Buffer characteristics of rigid polyurethane foam when subjected to static compression

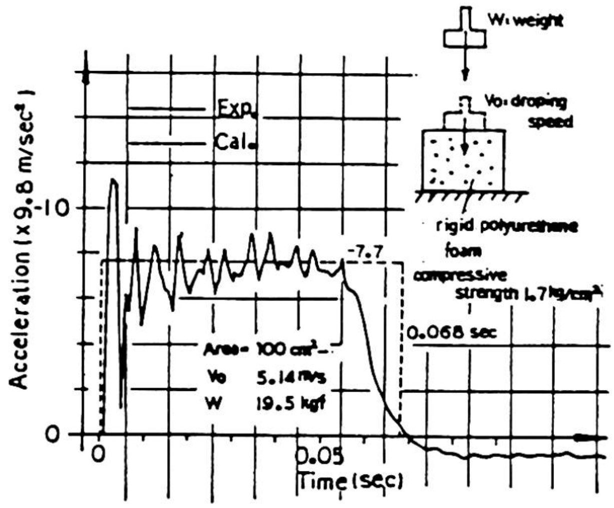


Fig. 6 Buffer characteristics of rigid polyurethane foam subjected to dynamic compression

4. APPLICATION TO PROTECTION DEVICES

4.1 Buffer equipments for the maritime structures

Buffer equipments will be installed for the maritime structures such as the piers of a bridge in a long span for the purpose of protecting both of them against impact forces when ships collide with them by mistake. An executed example of the buffer equipments is shown in Photo 2, and Photo 3. It consisted of steel shell stiffened by ribs, frames, etc., and the blocks of the rigid polyurethane foam which were filled in the room of the shell. This buffer equipment was tentatively installed for a long span bridge in 1981, and dismantled in 1983.

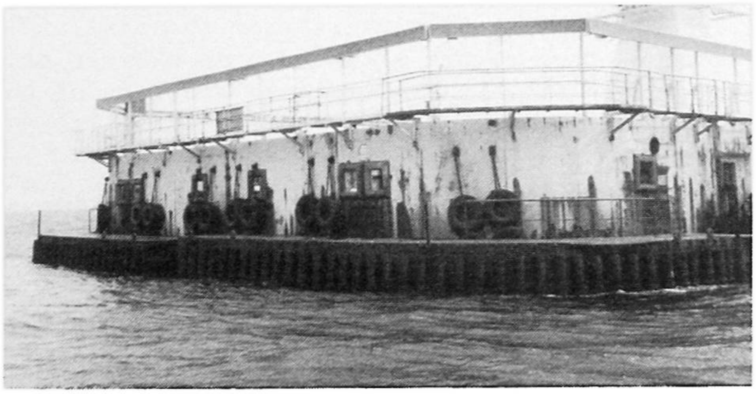


Photo 2.

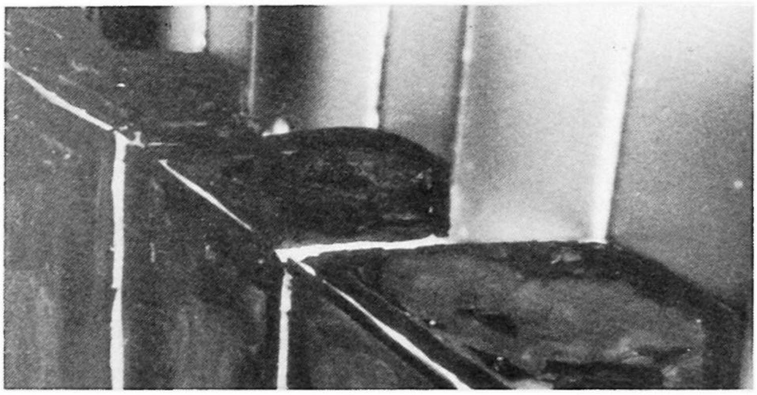
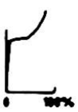


Photo 3.

Table 1 Rigid polyurethane foam and other materials

		Specific weight	Easiness of processing	Compressive strength	Load-deformation curve	Efficiency of buffer	Others: Merits	Others: Demerits	Main uses
Brittle chemical materials	Rigid polyurethane foam	0.2 ∫ 0.5 0.045*	○	0.5 kg/cm² ∫ 10 kg/cm² 1.4* kg/cm²		○ Over 80%	No directional difference of compressive strength, suitable for big buffers, low rebound force		Buffers
Firing organisms	Polyurethane foam, polyethylene foam, and other plastic foam	0.01 ∫ 0.5	○	0.2 kg/cm² ∫ 20 kg/cm²		△ Less then 60%		Unsuitable for big buffers	Adiabatic materials, floater
Firing inorganic matters	Firing concrete, binding pearlite or firing glass	0.3 ∫ 0.6	○	10 kg/cm² ∫ 40 kg/cm²		X About 30% About 30%	High-durability	High compressive strength, low compressibility	Adiabatic materials, soundproofing
Honeycombs	Paper, plastics aluminum	0.1 ∫ 0.3	X	0.5 kg/cm² ∫ 50 kg/cm²		○ Over 80%		Large directional difference of compressive strength	Light materials of structure (panel)

Note: The asterisked values are those used in the model experiments.

4.2 Protective structure of ship hulls

The structure of combined steel and the rigid polyurethane foam will be applicable to the protective structure of ship hulls for the purpose of preventing tankers from spilling oil, burning and especially for LNG tankers from the rise of temperature of LNG when they collide each other or are stranded. An example of the structure is illustrated in Fig. 7. The protective structure consists of the double-hull plating and the flame-resisting rigid polyurethane foam which is inserted in the gap.

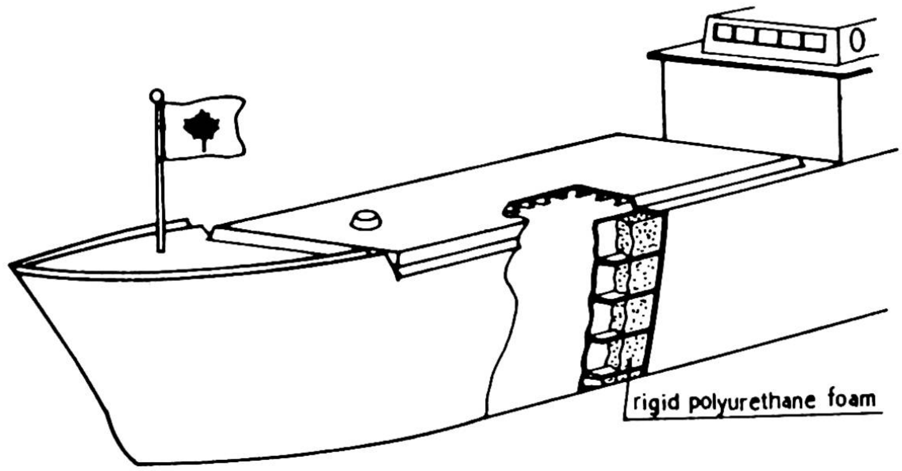


Fig. 7

4.3 Protective device on roads

When motorcars hit against the mounds at the intersection, side walls, guardrails, median strips on roads, the protective structures of combined steel, fiber reinforced plastics, rubber and the rigid polyurethane foam will obtain good results to keep them in safety. Examples of the structures are shown in Fig. 8. It is especially useful to reduce the dead weight of the bridge in a long span because of the light weight of the rigid polyurethane foam.

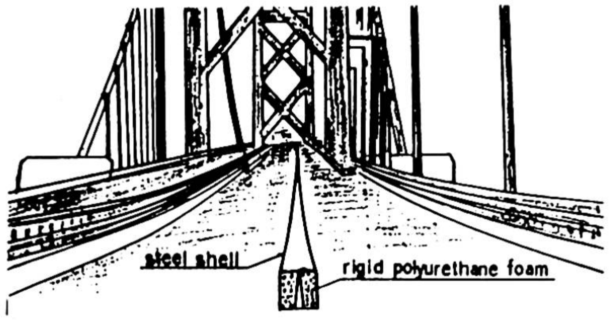


Fig. 8

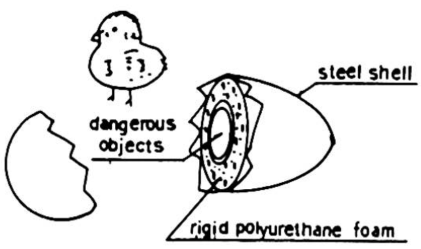


Fig.9

4.4 Receptacles for dangerous objects

It will become a serious issue that the receptacles for dangerous objects (ex. the radioactive waste matters) are damaged due to the drop impact under transport or casting away. The structure of combined steel and the rigid polyurethane foam, for example as shown in Fig. 9, will be applicable to the receptacles for the prevention of contamination of the circumstances.