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Study on a concrete filled steel structure for nuclear power plants (part 1). Outline of the structure and the mock-up test

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ABSTRACT : A mock-up test and various other structural tests on a new building structural system with a concrete filled steel structure, termed "SC structural system", were conducted. This paper presents the results from the feasibility study and various related experiments, which have shown the outlook for this application to be favorable.

1. INTRODUCTION

There have been several studies on the SC structure, and various basic experiments have shown that it has excellent strength and ductility.

It is thought that applying SC, makes it possible that the buildings of nuclear power plant have highly seismic capability ; and also, because of the SC's prefabricated nature, the buildings can be easily constructed.

However, the SC is expensive compared to conventional reinforced concrete structures (RC), and also has the disadvantage of requiring welding work. These disadvantages can be compensated for by using the thinnest possible steel plates (around 6mm) and employing steel bars at the joints.

We studied in detail the building structural system with SC based on the above mentioned concepts , and carried out a feasibility study of constructing an ABWR building by the "SC structural system" (refer to Fig. 1). In order to verify the results, confirmation of workability was conducted by tests on a full-scale model. Various experiments on structural properties were also carried out.

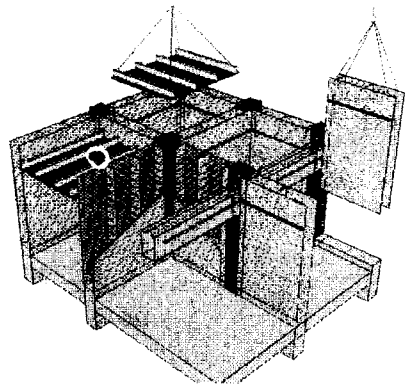


Fig. 1 Overview of SC structural system

2. SC STRUCTURAL SYSTEM

The walls, floors, columns and girders are all composed of concrete and steel plates with headed studs. Headed studs, being components that are highly workable, prevent thin steel plates from sectional buckling, and it is possible to flexibly design these diameters and pitches, in order to connect the plates and the concrete under various loading conditions.

(1) *SC Wall Members* : The steel wall panel shown in Fig.2 is factory produced. Two plates are connected to form a sandwich by means of tie-bars, and thus the shape is easily kept throughout transport, and deformation caused by the pressure from the concrete when it is filled after erection is also prevented. The normal pitch of studs is @20 cm.

When employed as shear walls, these panels are welded to each other, and assembled in the specified shape for resisting seismic forces. When employed as partition walls, the simple jointing method with steel bars is used to fasten the steel plates to the ceiling and floor. (Fig.3)

When laying pipework along the walls, the supports can be welded to any preferred position on the surface plates, and the headed studs attached to the steel plates also serve as their anchor bolts . (Fig.4)

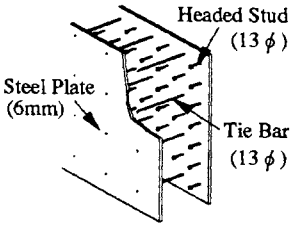


Fig.2 SC Wall Panel

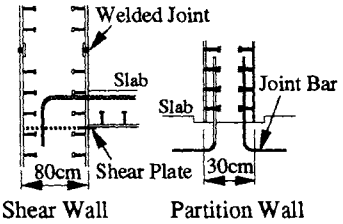


Fig.3 Wall Joint

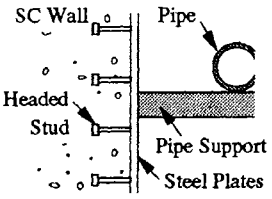


Fig.4 Pipe Support

(2) *SC Floors* : For floors, a steel plate is attached to only the bottom side, and a reinforcement mesh is placed at the top.(Fig.5) The reason a steel mesh is employed is that a flexible surface finish is possible, and anchoring can easily be achieved to the surrounding walls and girders. (Fig.6) Steel ribs are attached to the bottom plate, maintaining the shape of the panel while erecting and placing concrete. These ribs can also be utilized for enabling the prefabrication of the pipework attached to the bottom plate.

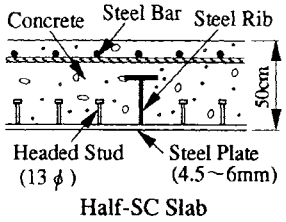


Fig.5 SC Floor

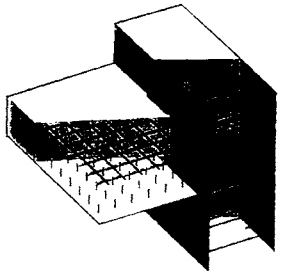


Fig.6 Wall-Floor Joint

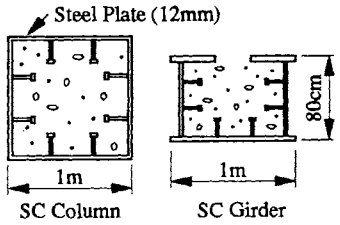


Fig.7 Column and Girder

(3) *SC Columns, Beams* : Columns and beams need to be rigid members, as they support heavy vibrating machinery. They consist of a concrete filled box-like steel casing. (Fig.7)

(4) *Construction Procedure* : When constructing the "SC structural system" , light SC panels of around 3 tonf produced in the factory are placed in the order of columns, girders, walls, and floor. (Fig.8) After setting up steel bars on the floor, concrete is filled with no formwork. Lastly the joints between panels are welded or sealed.

Since the construction period of the SC system is shorter, the subsequent interior machinery work can be completed 2 to 3 months earlier than for current RC buildings for nuclear power plants.

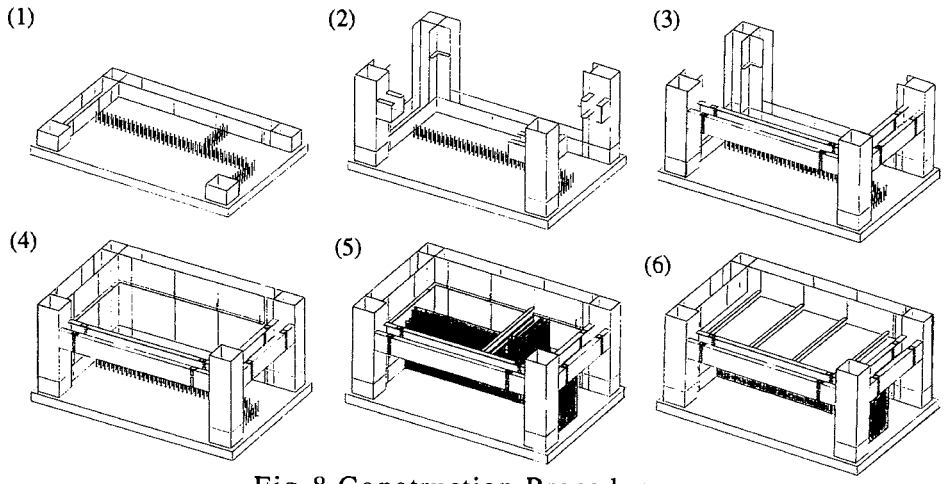


Fig.8 Construction Procedure

3. FEASIBILITY STUDY

Feasibility study was made to investigate the construction period, the material quantity and construction cost, and the manpower requirements, involved when an ABWR plant is constructed using the "SC structural system".

Rough design of the "SC" building was performed , based on the results of structural experiments, which will be mentioned later. An estimation of the quantity of construction material showed that a decrease of steel of around 20% is possible; forms also become unnecessary, (Fig.9) and the construction cost would be about the same as for RC buildings.

The total number of construction workers on the field will also decrease by around 30%. (Fig.10) Furthermore, because the "SC structural system" requires only the simple work of assembling the panels, filling the concrete, and straight welding, it is well suited for mechanized construction. Thanks to prefabrication, the construction period is 2 to 5 months shorter than that of a current RC building.

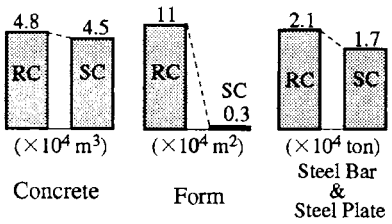


Fig.9 Material Quantity

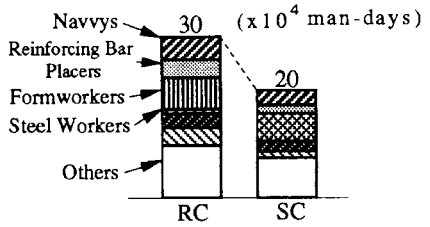


Fig.10 Manpower Requirement

4. OUTLINE OF THE STRUCTURAL PROPERTIES TESTS

To study structural properties and workability, experiments were conducted regarding 4 kinds of fundamental performance. The outline of the experiment for structural properties is given here.

(1) *Compression Loading Test* : In the SC structural system, effective use of headed studs prevents the buckling, and the thickness of the steel plates has been reduced. The objective of the experiment was to confirm at what pitch the headed studs should be welded for maximum economy. Moreover, this experiment confirmed that the concrete and the steel plates move in unison until failure.(Fig.11)
The experimental results are reported in Part 2.

(2) *Shear and Bending Loading Test* : The shear walls in question have the following characteristics: the steel ratio (surface plate thickness to wall thickness) is low (0.7～2%), there are various shear-span ratios, and the side borders consists of intersecting walls ("H" shaped) or columns.
The objective of the experiment was to evaluate the structural properties and performance of SC shear walls which model such characteristics. (Fig.12)
The experimental results are given in Part 3.

(3) *Wall-Floor Joint Experiment* : At the wall-floor joint, the floor concrete is divided by the wall's steel plates. In order to have the floor support heavy machinery and vibrating machinery, the joints' rigidity has to be evaluated, and sufficient joint strength must be achieved. The basic experiment given in Fig.13 was designed to study this.
The experimental results will be reported in the near future.

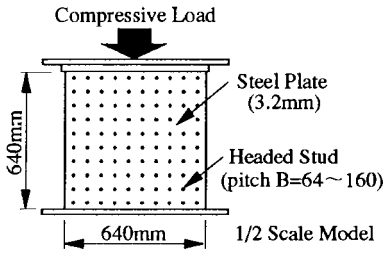


Fig.11 Compression Test

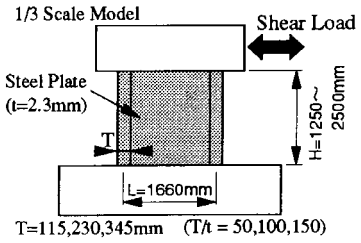


Fig.12 Shear and Bending Test

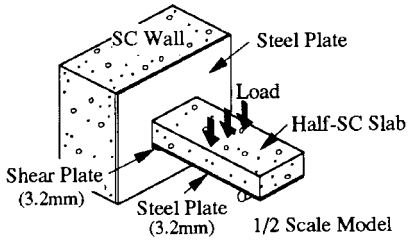


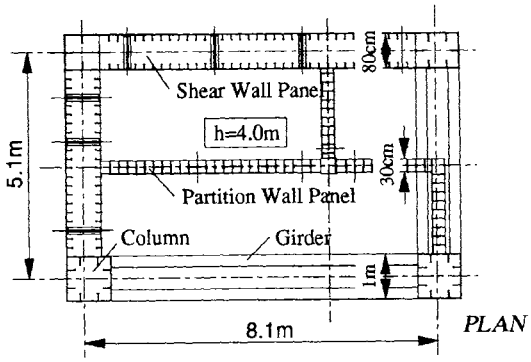
Fig.13 Wall-Floor Joint Test

5. MOCK-UP TEST

(1) *Objective* : One of the objectives is to examine the possible shortcomings, relating manufacturing and constructing. A lot of thin steel plates are used in the "SC structural system". The formation of surface ripples caused by welding heat, perforation of the steel plates by the headed studs may occur during manufacturing; also a problem is the degree of out-of-plane deformation when the concrete is filled.

Another objective is to evaluate the workability concerning with the ease of erecting these panels and filling with concrete, as well as the quality of the finished product. In order to study these objectives, a full scale model of height 4 m (1/2 scale) span 8 m x 5 m was built.

(2) *Outline of the Experiment* : An overview of the experiment is given in Fig.14 and Photo.1. The members indicated in Fig.2 to 7 were used.



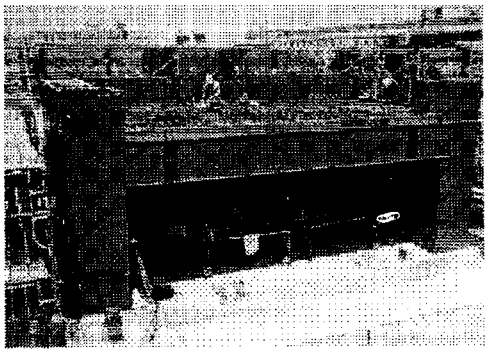


Fig.14 Overview of the Experiment Photo.1 Outward Appearance

Shown in Photos 2 to 5 are the completed wall, floor, column and beam. Almost no surface ripples occurred, and the precision of the measurements is ± 2 mm.

The panels were erected rapidly using a 4 ton crane. The panels assembled in sandwich form hardly underwent any flexing. (Photo.6,7) Ordinary concrete was used having a slump of 12 cm for the floor and 15 cm for the walls. The out-plane deformations of the surface plates were measured and came to only 2 to 4 mm. Also, because there were few obstructions within the panels, the concrete was satisfactorily placed with no air pockets. The state after interior painting is shown in Photo.8. Since the pipework supports can be welded to any position on the surface plates, the equipment pipework that will be carried out after the building construction should also prove efficient.

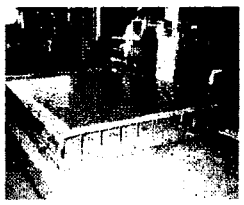


Photo.2 Wall Panel

Photo.3 Floor Panel

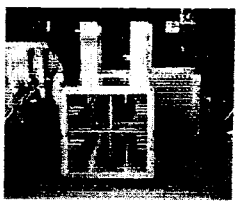


Photo.4 Column

Photo.5 Girder

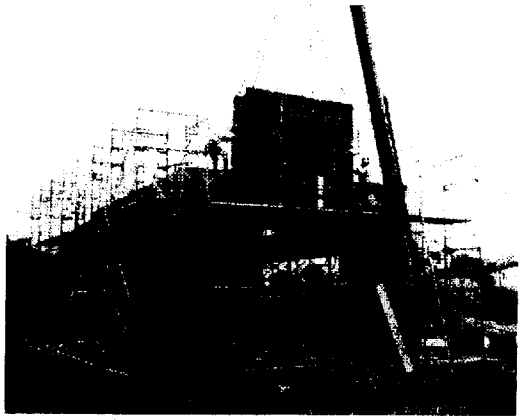


Photo.7 Panel Erecting

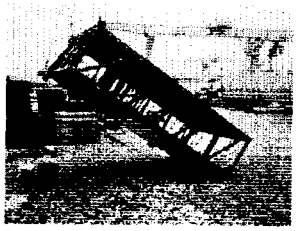


Photo.6 Suspension

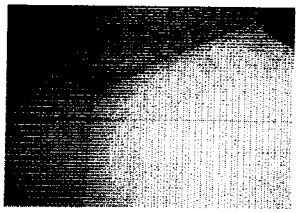


Photo.8 Finish View

6. CONCLUSION

A study on the SC structural system for nuclear power plants is summarized. Through the feasibility study and the related experiments, it has been evaluated that the SC system has excellent structural properties and that it also facilitates efficient building construction.

In the near future, the rational evaluation of structural properties will be developed. Durability and fire-proofing must also be confirmed, and are considered to be the important themes for future studies.

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