Combination of Flat Beams and Flat Slabs — Onomichi Deep Freeze Logistics Center, Japanese Consumers' Co-Operative Union —

フラットビームとフラットプレートのコンビネーション
— 日本生活協同組合連合会　尾道冷凍物流センター —


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Synopsis
The Onomichi Deep Freeze Logistics Center is a two-story externally-insulated reinforced concrete (RC) structure, serving as a warehouse for frozen goods. It has been built in Stage 2 of the site's development project, following the completion of the adjacent Logistics Center in Stage 1. In order to maximize its performance as a deep-freeze warehouse, the authors proposed the use of pre-stressed concrete flat beams for the roof and second-level floors, and flat plates on independent footings as capital for first-level floors. The structures on the site have been designed under the "pre-stressing" theme, including the connection bridge and the cable-stayed bridge framework for truck berths in Stage 1 structures.

Structural Data
Building name: Onomichi Deep Freeze Logistics Center
Location: Onomichi City, Hiroshima prefecture
Owner: Japanese Consumers' Co-operative Union
Design and supervision: Nikken Sekkei Ltd.
Contractor: Kumagaigumi Co., Ltd.
Site area: 9,211.54 m^2
Total floor area: 18,062.88 m^2
Number of stories: 2 stories above ground and a single-level rooftop shack
Maximum height: SGL + 16.20 m
Construction period: April 2011 – March 2012
(10 months + 2 months for cooling)

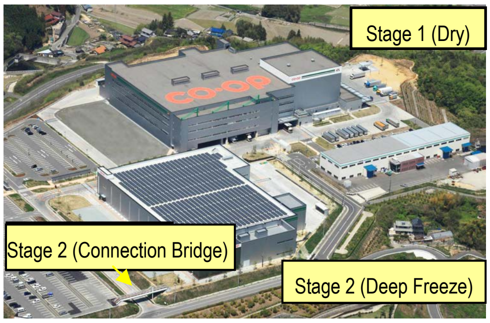

Photo 1. Overall view of building

1. Introduction
In response to the owner's request to maximize the structure's performance as a deep-freeze warehouse, prestressed concrete (PC) flat beams and RC flat plates were combined as a structural solution. This paper describes developments leading up to design finalization.

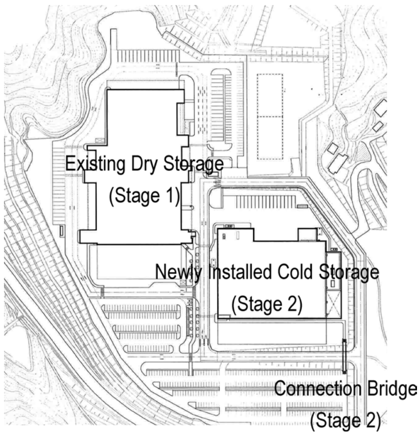

Fig. 1 Site plan

Photo. 2 External view of Stage 2 building

2. Overview of the architectural plan

(1) Basic policy for insulation design

Insulation is one of the essential functions for a deep-freeze warehouse. Insulation methods can be divided into "internal wall insulation" and "external wall insulation". In this project, it was firstly decided to adopt the "externally-insulated RC" approach in order to minimize the need for insulation work on the uneven surfaces of the structural framework and utilize the framework's thermal capacity to inhibit temperature fluctuations.

(2) Issues of the externally-insulated RC approach

Debates within the design team identified several issues, as listed below:

- Internal wall insulation is required at the boundaries of different temperature zones (e.g. -25 degrees Celsius and -10 degrees Celsius), creating construction constraints if the framework is very uneven.
- External wall insulation is required under the first level floor, and ventilation channels are also required to prevent the ground directly underneath the building foundation from freezing. However, they are difficult to incorporate due to interference with the foundation beams.

After trial and error, full adoption of the pre-stressing structural approach was decided to solve these issues, as detailed in the next section.

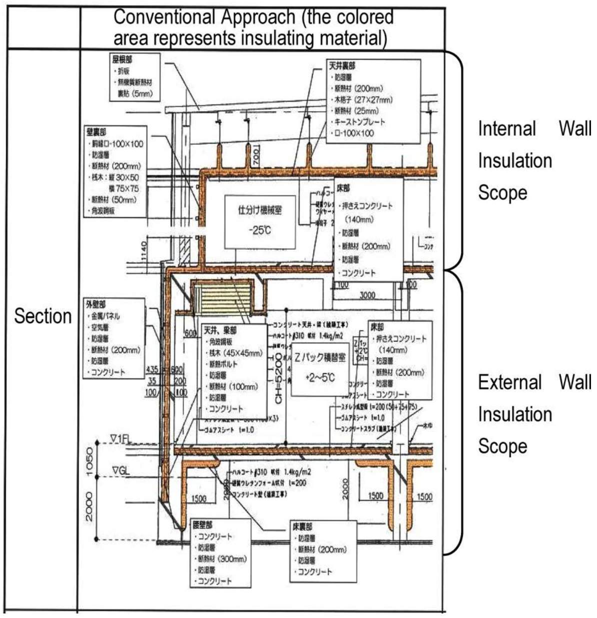

Fig. 2 Cross-section considered typical regarding external wall insulation

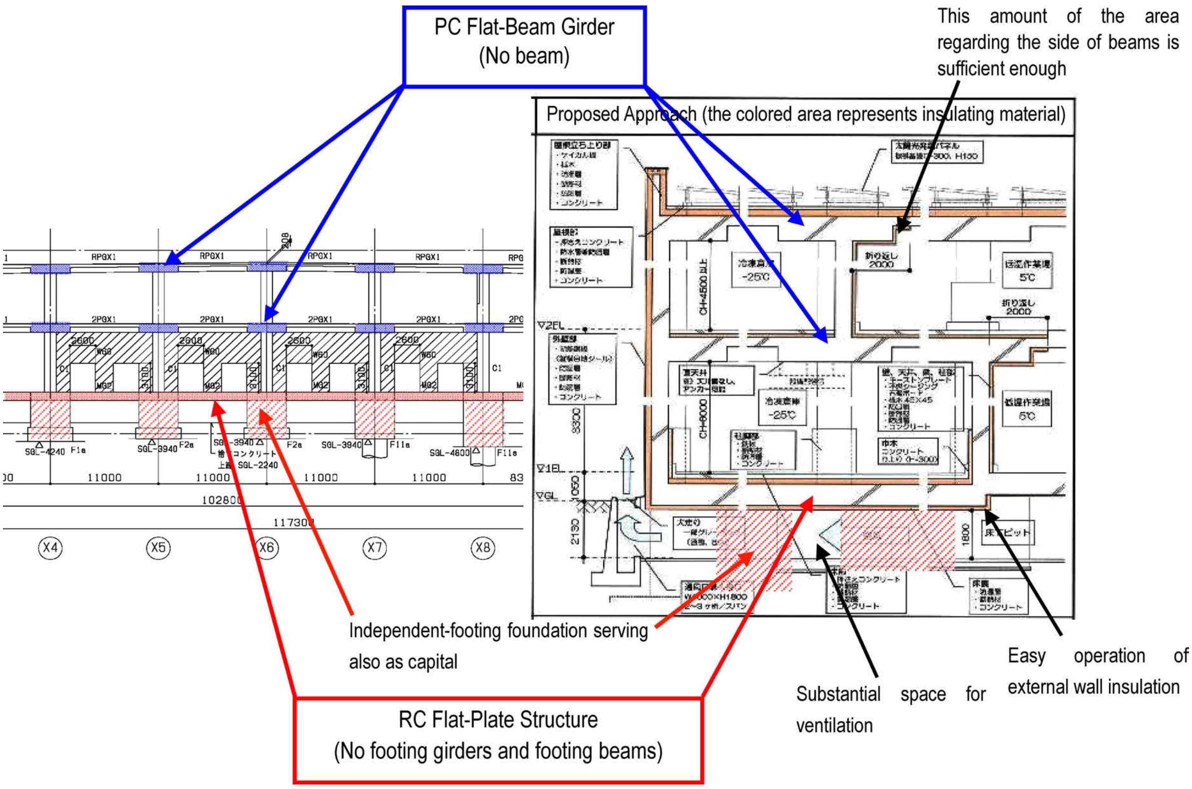

Fig. 3 Summary of structural system

3. Overview of the structural plan

(1) Proposal to use PC flat-beam girder (for the floors on the 2nd level and Roof level)

At first, the possibility of eliminating all the beam was explored, as the uneven surface they create under the floors would cause construction constraints for internal wall insulation, which is partially required. However, since the size of a base grid was 11.8m by 11.0m, using flat plates without girders and beams would require pre-stressing for the entire area and greater thickness, making the approach uneconomical.

Next, eliminating only the beams in a square-slab approach was considered. This case was unsatisfactory as well, as a small girder width would cause the slab span (inner measurement between girders) to be large, making it necessary to increase slab thickness due to the warehouse's need to bear a significant floor load.

That was when thoughts were given to the use of a flat beam system, measuring 200 – 400cm wide and 90cm deep, for girders. Even if the depth is small, having a large width enables the arrangement of sufficient PC steel materials. This allows installation over 11.8m with a relatively small girder depth in relation to the span. Reducing the inner measurement between girders also made it possible to keep the slab thickness to 350mm.

This approach has not only reduced the constraints in installing internal wall insulation, but also kept the floor height low for enhanced economy. The use of pre-stressing has also contributed to restraining cracks.

Photo. 3 PC flat-beam girder

Photo. 4 Minimizing the area regarding side of beams

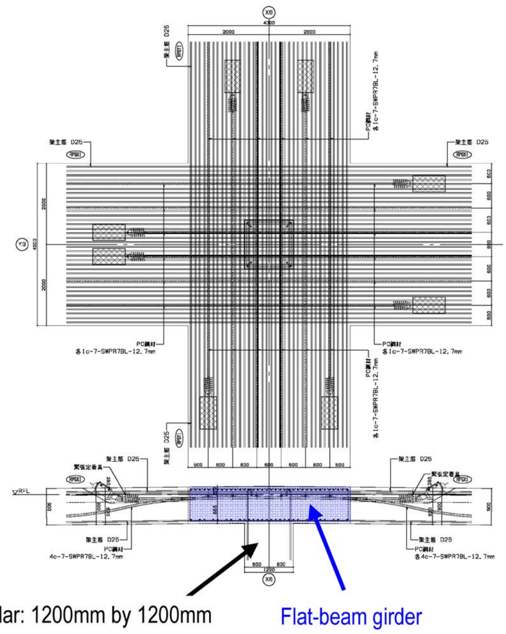

Fig. 4 PC flat-beam girder joint

(2) Proposal to use RC flat-plate structure (for the floor on the 1st level)

As described earlier, external wall insulation and ventilation are also required under the first-level floor. Initially, considerations were given for making ventilation holes on the side of footing beams under the first-level floor. However, the unevenness they create on the framework would create construction constraints, as in the case for the inside of the building.

The site's condition is very good, allowing the use of independent-footing foundation despite the extreme weight of the building. However, it was also known that the footing size needed to be up to 5m by 5m. It was therefore decided to apply the findings from our considerations for the 2nd and Roof levels, and explored the use of the flat-plate system, with the footings serving as the capital, while cancelling the use of footing girders and footing beams. Further considerations found that the use of 90cm-thick flat plates could eliminate the need for pre-stressing. This approach has fundamentally improved the under-floor ventilation and construction constraints for external wall insulation.

Photo. 5 RC flat plates

4. Focuses of the structural design

(1) Flat-beam girder design under extended load bearing

The building was, naturally, planned to have RC walls. Since the schedule made it difficult to post-cast upper walls, there was a possibility of pre-stressing on flat-beam girders being distributed to walls. For this reason, PC steel tendons have been introduced to cancel around 50% of the total weight with their lifting effect alone. They are shown as partially prestressed concrete in cross-section design.

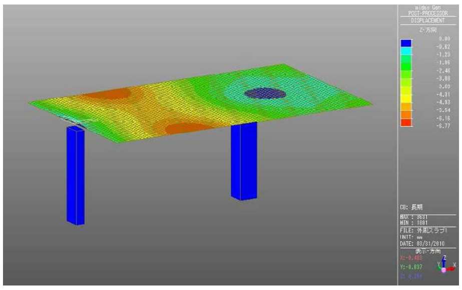

Fig. 5 Certification of elastic deflection with FEM analysis

(2) Countermeasures for concrete cracking

In addition to the pre-stressing effect, specifications for concrete and concrete overlay were set as shown below to counter possible cracking as much as possible:

- Limestone aggregate + Expansive additive(20kg/m^3), adopted after test mixing
- Use of high-performance AE Water Reducer to reduce the unit water volume to 170kg per square meter for the required slump value of 12
- The top reinforcement for the slab and concrete overlay (double reinforcement) @100
- Strengthened reinforcement to the corners of floor slab for the deep-freeze area and the edges of long walls

Photo. 6 Connection bridge modeled after Shin-Onomichi Bridge

(3) Further use of techniques

Although low cost and quick construction should be the primary aims in designing logistics facilities, the creation of an appealing structure for people who work there was sought for.

While designing the Stage 1 structure which was completed first, the owner's request to space out the truck berth pillars by proposing a "cable-stayed bridge framework" modeled after the Shin-Onomichi Bridge, which can be seen from the site, was addressed. Since then, it has been our desire to use as much tension structures as possible inside the Stage 2 building (if the designing contract were to be given to us).

That is why the pre-stressing design was fully adopted to the entire deep-freeze warehouse, and used a tension structure for the connection bridge linking the car park to the building over a road.

5. Conclusion

Succeeding in designing multiple structures on the site under a uniform concept has brought us a great sense of achievement and happiness as structural designers. It is our wish to express gratitude to the Japanese Consumers' Co-operative Union for the opportunity.

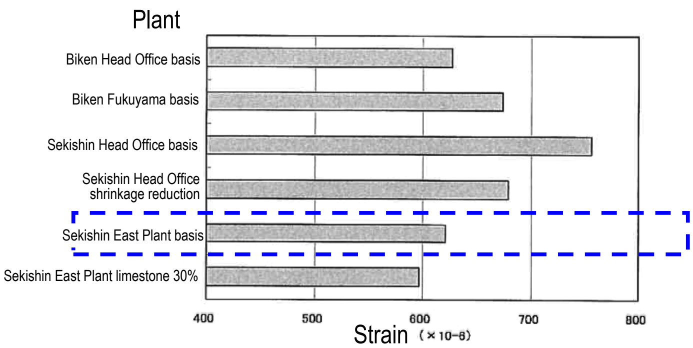

Fig. 6 Measurement of dry shrinkage strain by test mixing

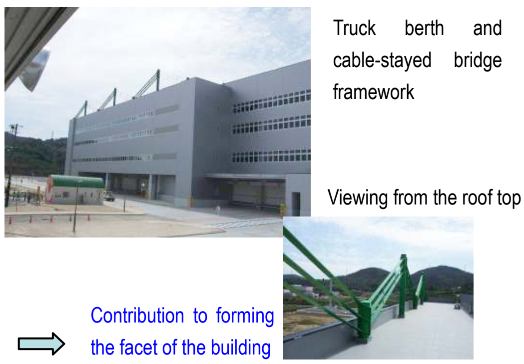

Photo. 7 Truck berth of Stage 1

概　要

尾道冷凍流通センターは，RC 造外断熱・2 階建ての冷凍倉庫であり，隣接する第 1 期工事の流通センターに続く第 2 期工事である。冷凍倉庫の性能最大化を目指し，屋根と 2 階床にはプレストレスを導入したフラットビームを，1 階床には独立基礎をキャピタルとしたフラットプレートを各々提案した。連絡橋や第 1 期建物内トラックバース部の吊り橋架構を含め，敷地内建物の構造設計を「プレストレス」をテーマにまとめ上げている。