Large scale XPS bulk-up for a major construction project

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1.Summary

This paper describes a typical example of the expanded polystyrene (XPS) bulk-up of buildings in Japan. About 4,000 m^3 of expanded polystyrene was used as bulk-up material to reduce the vertical load of vegetation landfill, raising the structural material and thermal insulation to be fitted over the shell-dome of a large gymnasium.

2. Design

The gymnasium is a group of athletic facilities designed for various international sporting events. All structures at the facility are constructed under the ground of a park, the intention being to utilize the site effectively and preserve the environment in an urban area. Structures making up the facility include the main arena with a diameter of 110m, height 30m and seating for 10,000, plus a sub-arena, judo hall, and fencing hall. (Fig.1)
This construction work is revolutionary plan combining a park with luxuriant vegetation with large structures in a major urban area with little greenery.
The roofs of the main arena and the sub-arena support landfill and vegetation around 1m thick in the park above the ground. They are covered with vegetation to give the appearance of an ancient burial mound.

(1) Structural design
The total weight of the main arena roof is around 700,000 KN (approximately 5-6 tf/m^2). A spherical shell structure of prestressed concrete was employed for the large span roof, supporting this huge weight. (Fig.2)
(2) Design concepts
1) To create a comfortable space in the arena without consuming energy on air-conditioning, by utilizing effectively the thermal characteristics of the site, such as the constant temperature and high thermal insulation underground.
2) To utilize natural energy, including natural ventilation and lighting.
3) To utilize the roof of facility as a park by installing all structures underground and covering the roof with the soil and green plants.
(3) Description of buildings
Total site area: 123,986 m^2
Total construction area: 408 m^2
Total floor area: 42,665 m^2 (B1-B3)
Height of highest structure: +30.0 m (Basement 3)
Foundations: RC continuous underground wall and on-site set concrete pile
Overhead structure: Roof of arena, spherical shell structure of prestressed concrete (Photo.1, Photo.2)
Other: Reinforced concrete structures and prestressed concrete structures

3. Production of expanded styrol

Expanded styrol is made from polystyrene (solid), a polymerized product of styrene monomer obtained by combining petroleum and a foaming agent. Two types of EPS are available, manufactured using different methods: EPS (expanded polystyrol) made by mold foaming, and XPS (extruded polystyrol) made by extrusion foaming.

(1) Mold foaming (EPS)

The mold foaming method involves a series of processes to obtain the molded product, including preliminary foaming of polystyrene beads obtained from the polystyrene and foaming agent; drying and curing of the pre-foamed beads in a silo; packing the beads into a molding machine; heating the beads until they soften, and final cooling. (Fig.3)

(2) Extrusion foaming (XPS)

In the extrusion foaming method, the polystyrene is heated and melted in an extruding machine, then mixed with carbon hydroxide gas to obtain fluidized gel. The gel is extruded and foamed to the molding unit, which is kept at a low pressure, from an orifice located at the tip of the extruding machine. (Fig.4)

(3) Characteristics of foamed styrol

The dynamic characteristics of foamed styrol vary in accordance with its weight. Compression is elasto-plastic. The compressive strength of foamed styrol has been determined by testing (JIS K 7220) to be equal to the compressive stress under a 5% strain. Plasticity is already limited however at stress of 5%, and deformation will remain if repeated charging is carried out at this load. The area in which elasto-plastic behavior is demonstrated for repeated loads corresponds with the proportional limit of compression at compressive strain of less than 1%. The load is about half of the compressive strength at this time. For this reason, compressive strength using this design is assumed to be 1/2 of the 5% compressive strength .

Fig.5 shows the relationship between the compressive stress and strain of extended polystyrene with different densities.

Thermal insulation performance also varies in accordance with density. Values of the extruded polystyrene (XPS) and expanded polystyrene (EPS) are 0.027 – 0.037 W/m?K and 0.034 – 0.044 W/m?K, respectively, indicating that the extruded polystyrene has better thermal insulation.

4. Measures taken in the design of these structures

(1) Problem

The problem with this design is the extremely high load of landfill on the roof. The maximum thickness from the slab surface of the body to the finish surface may be as great as 4m. The weight of landfill for a height of 3m needs to be reduced, because very high stress may be applied to the slab when ordinary landfill material is used. The thermal insulation performance of high thermal characteristics must also be considered, as a warming effect is required to minimize the energy consumed in air conditioning.

(2) Action

The EPS method was employed to reduce the load of landfill described above. Landfill material is used to reduce vertical loads, which protects the structure. The load on the body structure is reduced by filling with lightweight material of 1/100 the volume of the soil, making possible a design with reduced construction costs. As thermal insulation performance is also required, extruded polystyrene (XPS) was chosen because it has superior heat insulation to expanded polystyrene (EPS).

Slab concrete was constructed over the lightweight landfill material at several locations. When steel reinforcement for the slabs was laid, spacers were placed in order to assure a sufficient thickness of covering for the steel reinforcement. A concentrated load of 1 KN/location is usually applied to the lightweight landfill material through spacers. This implies that a load of 100 KN/m^2 is acting on the top surface of the lightweight landfill material. While expanded polystyrene is normally used, the concentrated load applied on the top surface of lightweight landfill may exceed the allowable load of the landfill material, resulting in plastic deformation. (Fig.6, Photo.5)

$$\mathbf{s} = 1\text{KN}/(10\text{cm} \times 10\text{cm}) = 100\text{KN/m}^2 > \mathbf{s}_{(D\text{-}20)} = 50\text{KN/m}^2 \quad \textbf{OUT}$$

$$> \mathbf{s}_{(DX\text{-}29)} = 140\text{KN/m}^2 \quad \textbf{O.K}$$

The landfill material used is required to have a compressive strength of at least 100 KN/m^2. As this exceeded the allowable stress of D-20 and D-25, we employed DX-29 extruded polystyrene (XPS) with high compressive strength. Deformation is prevented by adapting to load within the elastic region, and a sufficient covering of steel reinforcement provided without causing deformation as a result of the load during reinforcement laying work.

Cracking of concrete is a concern when slab concrete is placed directly over lightweight landfill material. The cracking of body concrete was prevented by using extruded polystyrene (XPS), which experiences only slight strain compared to expanded polystyrene (EPS).

5. Conclusion

The effects of the EPS process on reducing roof load may be summarized as follows:

(1) Using the EPS process made it possible to design for reduction of the vertical load equivalent to about 54 KN/m^2, decrease load on the body structure, and minimize costs.
(2) Using lightweight landfill material allows installation by hand and the need for large and heavy construction machinery is eliminated, in contrast to the use of ordinary soil. This means reduced construction time and costs, plus less noise due to the absence of heavy machinery.
(3) Using extruded polystyrene (XPS) with its higher thermal insulating power as the bulk-up material reduces the power required to run air conditioning leading to lower maintenance costs.
(4) Strain generated at the top surface of the lightweight landfill material can be controlled under concentrated stress by using material with a high compressive strength.
(5) Using vegetation to protect the exposed surfaces of structures reduces the deterioration of waterproof layers and walls as a result of acid rain and ultra-violet radiation, and the durability of buildings is also improved.

Vegetation is replaced by concrete in the modern urban environments in which we live, and abnormal microclimates known as “heat islands” produced by the huge volume of waste heat.
Environmental problems are growing on a global scale, and environmental issues shifting from “issues of recognition” to “issues of practice” as shown by the Global Summit held in June 1992.
Environmental problems will not be solved unless we can guarantee the coexistence of future buildings and vegetation.

The effects of planting vegetation include:
- Cleaning up the urban atmosphere
- Improving urban climates (reduction of heat islands)
- Energy savings (less spent on air conditioning)
- Retarding rainwater flowing off
- Improvements to urban scenery
- The creation of a “more harmonious and comfortable” environment
- Creation of recreational space

The effective utilization of building roofs is essential in the construction of large-scale athletic facilities in areas adjacent to natural parks, as illustrated by our study. Reducing the vertical load of green plantation soil by the EPS process allows us to design this type of nature-integrated construction.

In the bulk-up work that is the subject of this paper advanced application of the compressive resistance and heat insulating capability of the extruded polystyrene (XPS) contributed greatly to reducing construction time and costs. This is a successful illustration of the advantages of using extruded polystyrene in construction design.

References

1) Foamed Polystyrene Construction Process Development Corporation: Design manual, April 1993
2) Foamed Polystyrene Construction Process Development Corporation: Construction and cost estimation manual, November 1990
3) Foamed Polystyrene Construction Process Development

Corporation: Materials manual, April 1992
4) Foamed Polystyrene Construction Process Development Corpora

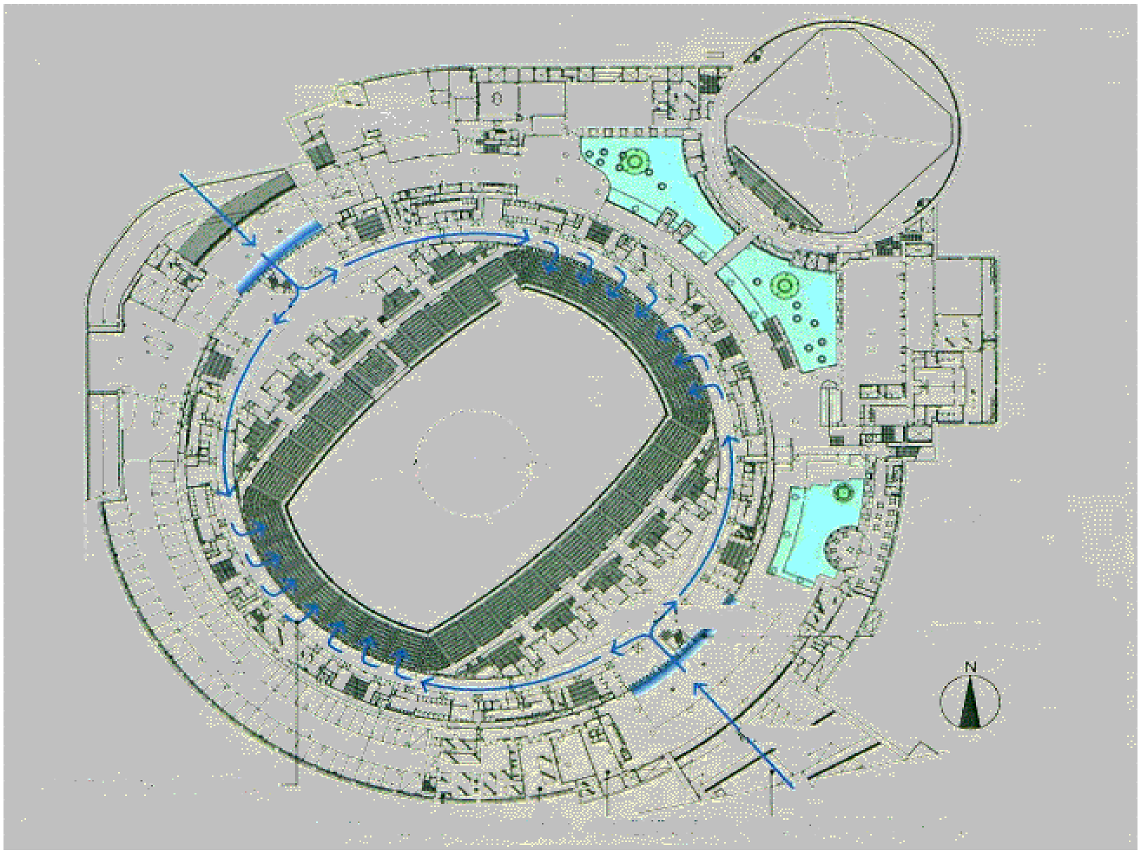


Fig. 1 Horizontal view

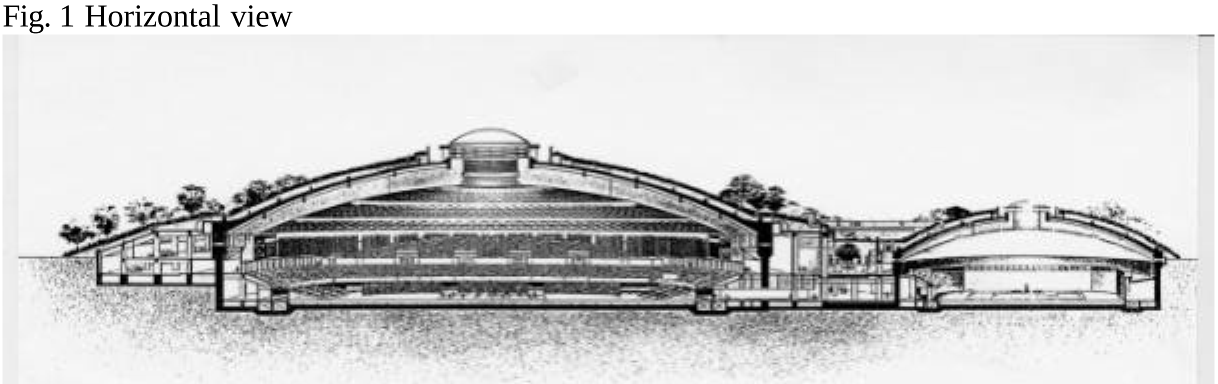


Fig.2 Cross-section of the gymnasium

Photo.1 arena

Photo.2 Construction of shell dome

? Delivery of raw materials ? Preliminary foaming ? Curing ? Molding ? EPS block

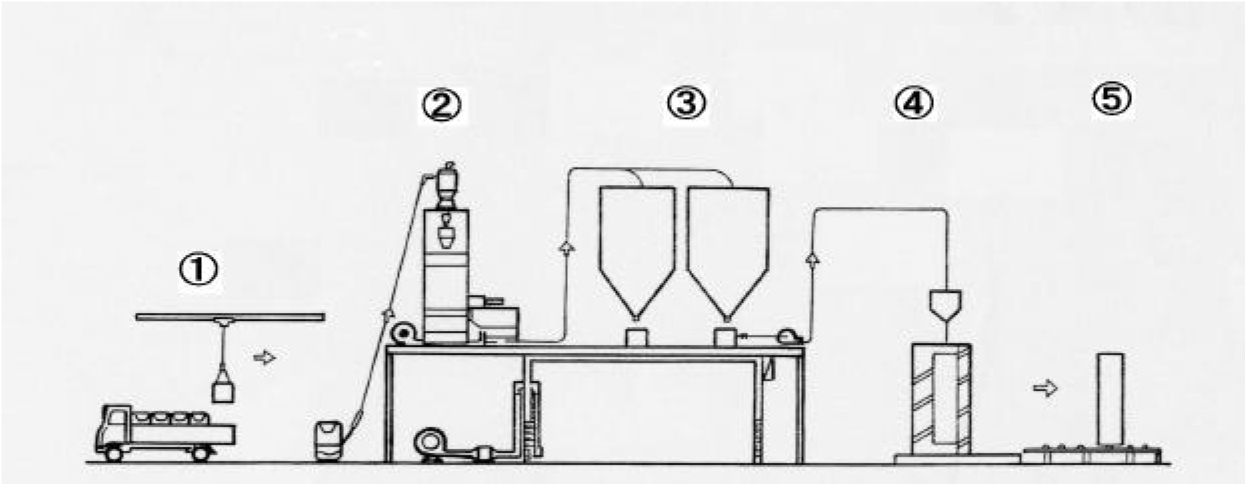


Fig.3 Manufacture of EPS

? Raw material goes in ? Raw material tank ? Stock tank ? Feeding unit ? Foaming agent ? Extruding machine ? Curing ? Cutting unit ? XPS block

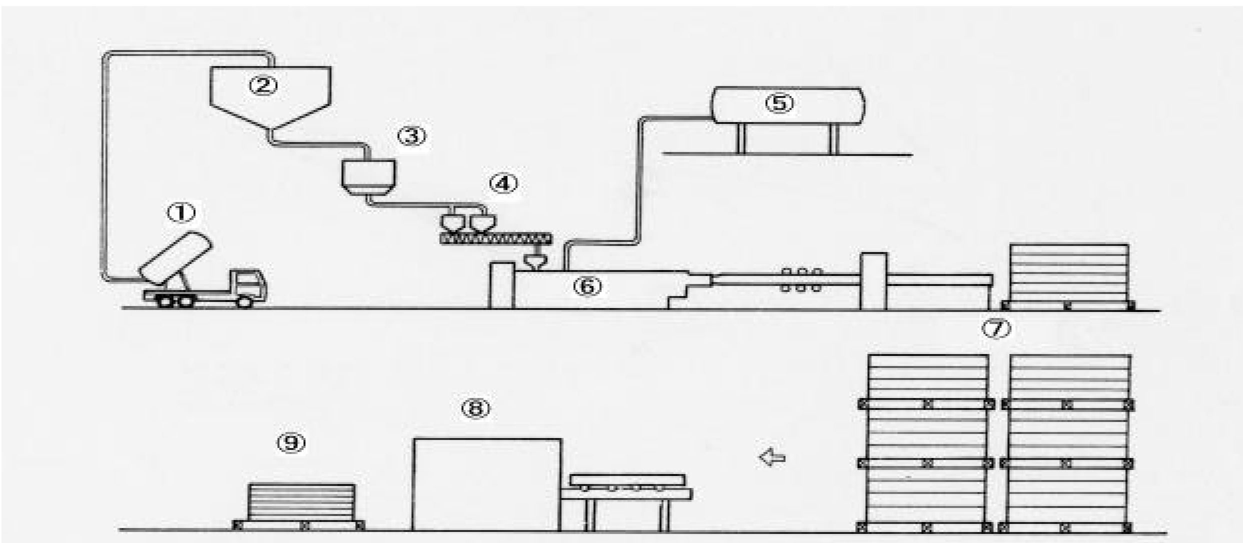


Fig.4 Manufacture of XPS

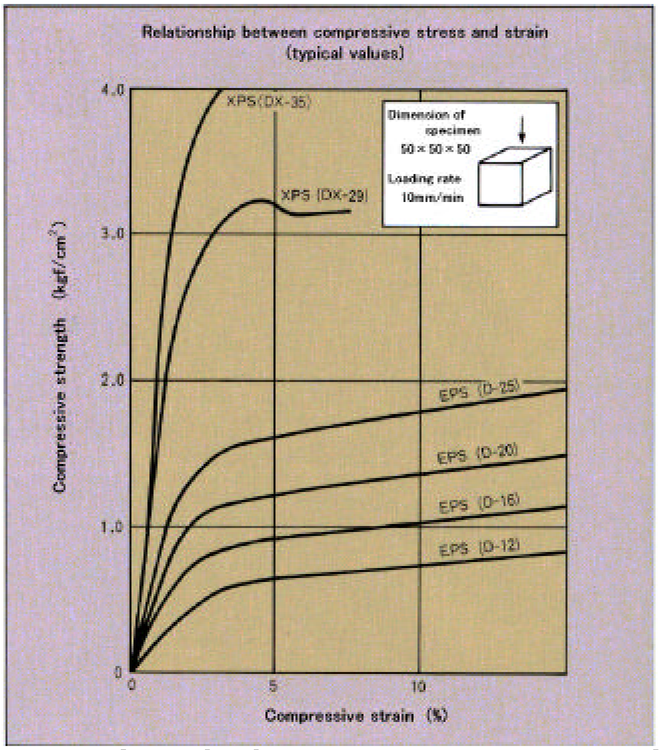
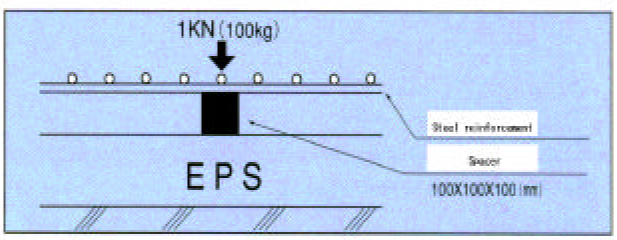


Fig.5 Relationship between compressive stress and strain of XPS and EPS

Table 1 Material characteristics of EPS and XPS

Item	Testing method	Unit system	Unit	Manufacturing method							Remarks
				Extrusion foaming		Mold foaming	Extrusion foaming	Mold foaming			
				DX- 35	DX- 29	D- 25	DX- 24	D- 20	D- 16	D- 12	
Unit volume weight	JIS K 7222	SI	kN/m^3	0.35	0.29	0.25	0.24	0.20	0.16	0.12	
Allowable compressive stress	—	SI	kN/m^2	200	140	70	60	50	35	20	Compressive elasticity
Quality control Compressive stress	JIS K 7220	SI	kN/m^2	400 or higher	280 or higher	140 or higher	120 or higher	100 or higher	70 or higher	40 or higher	At 5% strain
Allowable temperature	DOW method	SI	?	80	80	80	80	80	80	80	
Combustibility	JIS A 9511	—	—	Accepted	Accepted	Accepted	Accepted	Accepted	Accepted	Accepted	
Size of block	Length×width×thickness (m)			2.0ﾗ 1.0ﾗ 0.1~ 0.5 (Laminated product)		2.0ﾗ 1.0ﾗ 0.5	(Laminated product)	2.0ﾗ 1.0ﾗ 0.5			

Photo.3 Photograph of application work
Photo.4 Photograph of application work



XPS·EPS	Allowable compressive stress(KN/m2)	Safety factor
DX-29	140	1.4 (OK)
D-25	70	0.7 (NO)
D-20	50	0.5 (NO)

Fig.6 Cross-section of slab reinforcement laying work
Photo.5 Photograph of reinforcement laying work

Photo.6 General view of construction in progress
Photo.7 General view of completed construction work

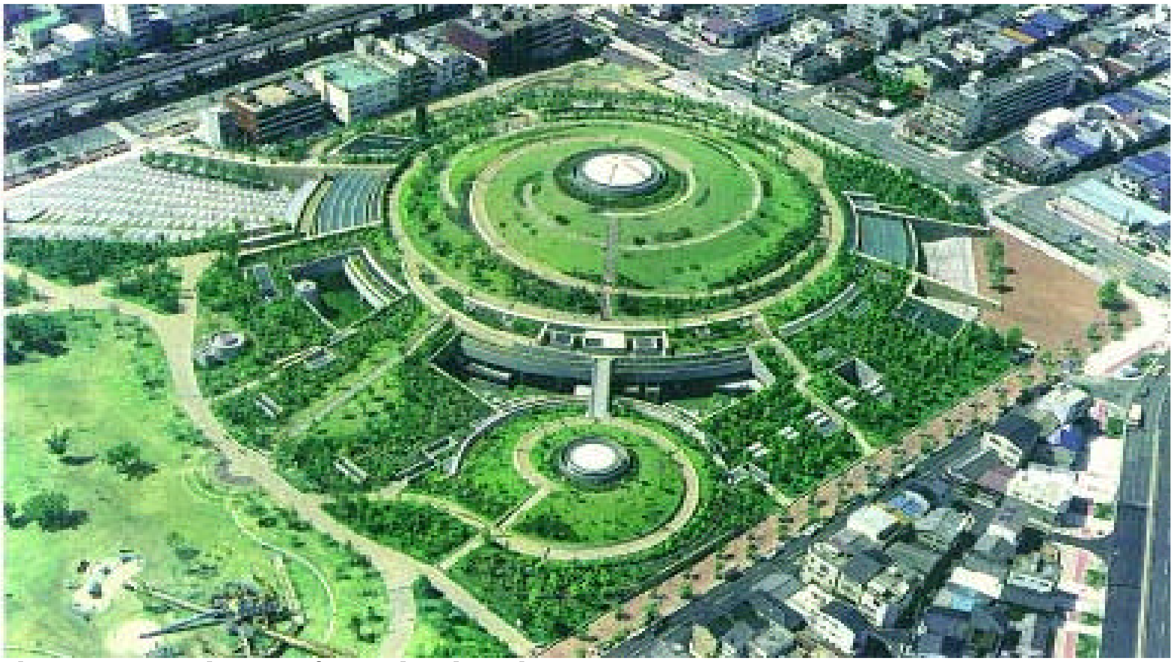


Photo.8 General view of completed work


Photo.9 Completed work