The Nhava Sheva silos, India

S.A. Reddi, Gammon India Limited, Bombay, India.
N. Prabhakar, Consulting Structural Engineer, Bombay, India.

Introduction

A new port has been constructed near Bombay. The port's bulk handling facility, with a capacity of 12 million t/year, includes four horizontal silos for storage of fertilisers, grain and sulphur, each with an area of 21 000 m^2. The design and construction of the four silos (Fig.1) involved consideration of both dead loads and superimposed loads from the conveyor and equipment besides wind and seismic forces, ecessitating extensive use of precast and post-tensioned prestressed concrete units.

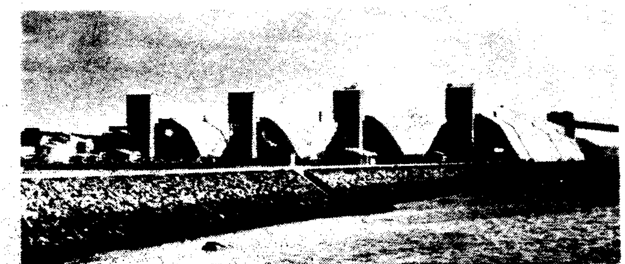

Fig. 1 General view of silos

Fertiliser silos

The two silos (Fig.2) are parabolic in cross section, 42 m wide x 21.5 m high x 499 m long. Each silo is made of 355 No 1.4 m wide concrete arch units, each arch unit comprising six curved elements of a trough-shaped section with a crown member at the top. The silos are partially prestressed both transversely and longitudinally. Expansion joints are provided at approximately 39.5 m centres. The arch units are supported on concrete hinges, resting on continuous strip foundations.

The 1.4 m wide x 0.8 m deep trough section offered an economical profile with an average slab thickness of only 160 mm, which is relatively thin for a 42 m span when the stiffness of the section is 39 times greater than that of the slab.

Each silo is fed by a 7.25 m wide x 7.5 m high conveyor gallery at the top with AC sheet cladding. The conveyor stools are supported on precast concrete tripper beams spanning 1.4 m longitudinally between the arch units. Precast

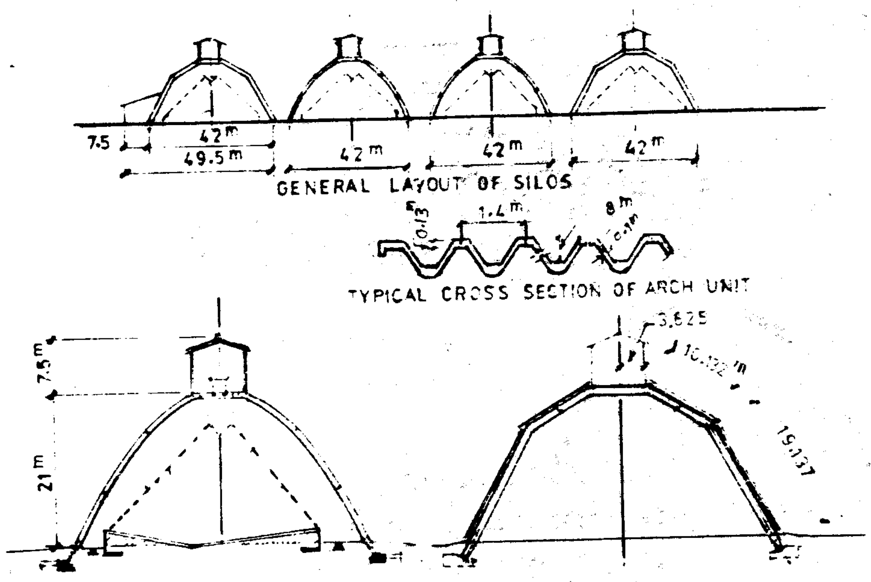

Fig. 2 Details of silos

concrete walkway platforms are provided on either side of the conveyor.

At floor level, 2 m high reinforced concrete retaining walls 30 m apart contain the materials, in addition to a foundation for the railtracks of a travelling scraper reclaimer and a recovery conveyor. The gable ends are covered with reinforced concrete walls and columns. The floor between the retaining walls consists of 75 mm thick bituminous concrete laid over a sloping sub-base of hardcore material. The remaining area has granolithic flooring.

Grain and sulphur silos

The silos (Fig.2) are 42 m wide x 21.5 m high x 499 m long. The structural arrangement consists of RC portal frames with AC sheet cladding supported on reinforced concrete purlins at 7.41 m centres. Each portal frame comprises two sloping leg elements and one central crown element. The profile of the frame closely follows the parabolic shape of the fertiliser silos. The lateral stability of the structure is provided by 10 200 mm diameter mild steel pipes between the portal frames, and by diagonal bracing between two adjacent frames at eight bays. Expansion joints are provided at approximately 126 m centres. The portal frames rest on concrete hinges and independent footings. Other structural details are similar to those of the fertiliser silos.

Foundations

The silos are located in an area reclaimed to a depth of 6-7 m. The top 1 m was made up of granular material with no more than 15% of the material finer than 75 microns, compacted to 98% standard Proctor density. Based on field tests, the gross bearing capacity of soil considered in the design is 12 t/m^2 at 2.2 m below the finished grade level, with a 25% increase under wind/ seismic loading.

Design aspects

The fertiliser silos are designed as two-hinged parabolic arches. Wind force is the major external applied load. The basic wind pressure considered in the design is 1.5 kN/m^2. The coefficient of wind pressure distribution acting normal to the parabolic profile is +0.51P active pressure on the quarter length of the arch on its windward side, -0.45 P suction on the quarter length on the leeward side, and -1.0 P suction on the remaining half length of the arch. Besides these pressures, an internal pressure of 0.2 P, or an internal suction of -0.2 P, is considered. In the earthquake resistant design, a horizontal seismic coefficient of 0.04 is considered. The seismic forces are applied in the transverse direction. Wind and earthquake forces are not considered to act simultaneously. Live loads of 0.4 kN/m^2 and 5 kN/m^2 are considered on the arch and platform respectively at crown level.

The structure is analysed as a two-hinged plane frame using stiffness matrix programming for various combinations of load. The calculated maximum deflection under service conditions, including wind, is 23 mm vertically and 38 mm horizontally, while the maximum rotation at hinge level is 0.0038 radians. Under wind load, large bending moments do occur along the arch profile, causing tension at the intrados on the windward side and the extrados on the leeward side. The tensile stresses in the concrete of the uncracked arch section are held to about 1.5 N/mm^2 by partially prestressing the arch. To form a cohesive and integral structure, arch units are longitudinally prestressed at six locations in the arch profile, and at crown level.

A travelling scaffold was used to support precast elements of the arch units between the expansion joints during erection. Once the in-situ joints between the precast elements were cast and matured to 15 N/mm^2 strength in 36 hours, the travelling scaffold was moved to the next bay, prior to prestressing.

Grain and sulphur silos

The frames are designed as two hinged plane frames. The portal frames are subject to loads from the feeder conveyor, conveyor gallery, and from platforms at crown level in addition to loads from the roof, wind and earthquake forces. The conveyor stools are supported on two reinforced concrete tripper beams. Wind forces form the major applied loading at a basic wind pressure of 1.5 kN/m^2. The calculated maximum deflection under service conditions, including wind, is 47 mm vertically and 85 mm horizontally, and the maximum rotation at hinge level is 0.0082 radians, which is well within the permissible values. M25 grade concrete and high-yield deformed bars are used for the portals.

The location of the joint between the precast elements was selected where the bending moment acting at the section is a minimum, keeping in mind the weight of the precast elements to be erected. The loads are transferred through the welded splice plates. The reinforcement detailing of the half-joint also required careful consideration as the concentration of high stresses in the region necessitated closely spaced rebars.

The foundation design

Flat-bottom foundations rest on uniformly compacted strata at about 2.2 m below grade level. The horizontal component of the loads on the foundation is resisted by friction between the concrete and soil and by balancing horizontal loads from the foundations of adjacent silos with interconnected tie beams. In order to improve their performance, saddle-bearing type, precast RC hinges (concrete M40) were provided for all the four silos after conducting a full-scale test of the hinges.

Production of precast members

Extensive precasting was resorted to for competing the silos within the short time of 10 months. The concrete quantity precast is approximately 20 000 m^3 with the maximum size of precast units weighing up to 30 t. The portal components were precast on rail-mounted falsework near the place of erection. The formwork was fabricated in large panels with only two vertical joints, thus minimising grout leakage. The side panels were demoulded about 200 mm sideways using turnbuckles to facilitate the lifting of the precast members, which could be moved for storage 48 hours after their concreting and curing.

The members for the fertiliser silos were precast in a central yard with equipment facilities for handling shuttering, reinforcement and concreting, and also for the transportation and storage of the precast elements. As the arch units were to be doubly curved, the mould had to be conceived with a view to ensure easy placement of the concrete and the removal of precast members immediately after steam curing, without damage. The moulds are of brickwork lined with mild steel plates. All corners were rounded off to avoid damage. The moulds were located with the top at ground level to facilitate concrete placement and minimise heat losses during steam curing. Reinforcement cages for the precast elements were prefabricated as a parallel activity.

Low-pressure steam curing was used in order to ensure a production cycle of 24 hours. After removal to the stacking yard, water curing was continued for seven days. The pre-steaming period normally equals the initial setting time of concrete which, in turn, depends upon the type of cement used, the mix proportions, and the ambient temperature. The high ambient temperature prevalent in India results in a shorter initial setting time of concrete. Based on experiments a presteaming period between 1-2 hours was found appropriate.

The rise in temperature from ambient conditions to 70°C. was achieved in about 2 hours. The soaking period of 4 hours was based on the requirements of the strength of the member to sustain its own self-weight of 15 N/mm² at the time of demoulding. The off period was similar to the temperature rise period. Tarpaulin hoods were used to enclose the steam curing chamber. The layout of the steam pipelines and nozzles was designed to ensure a uniform injection of steam. The top shutters were removed after steam curing. Additional test cubes were cast, steam cured along with the prestressed concrete elements, and tested for strength prior to their demoulding.

The concrete was supplied by a central batching plant, transported by 2 t capacity dumpers and placed in moulds. Compaction was realised by needle/shutter vibrators. An oil-fired boiler of a 1 000 litre/hour capacity generated the steam. The working hours of the boiler were reduced by:

- Suitably bunching the concrete pours for the arch elements
- Increasing the concreting speed
- Allocating fixed hours (usually during the night), and shutting off the boiler some time after the maximum temperature was reached, instead of operating for the full soaking period. The temperature inside the insulated chamber could be maintained for the soaking period after shutting off the boiler.

About 76 000 m^3 of concrete of various grades, including 20 000 m^3 for the precast members, was provided. The mix design for various mixes was done at the site laboratory, considering the method of production, transportation and placement of concrete. The major portion of the cement (conforming to BS 12) was supplied in 1600 Kg. jumbo-sized polythene bags, and handled by a wheel - mounted 5 t crane with a telescopic boom. The aggregates were obtained from nearby quarries. Due to variations in the grading, aggregates from two sources were blended.

In the case of the arch elements and purlins, the thickness of the member and its shape dictated the use of high slump concrete. Plasticisers were used to increase workability and a better surface finish, eliminating blow holes. Surface retarder was used to prepare surfaces for the construction joints. A

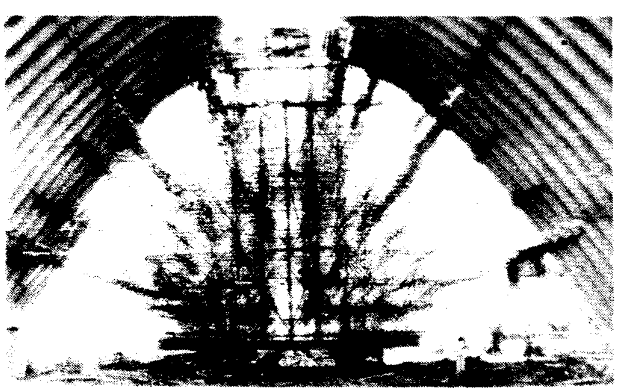

Fig. 3 Erection of fertiliser silos

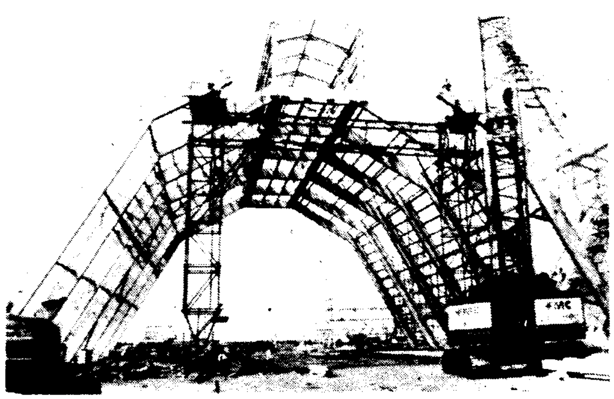

Fig. 4 Erection of grain and sulphur silos

curing compound was used, after extensive tests as per ASTM standards, for the concrete of in-situ joints due to their inaccessibility for normal curing.

Erection of silos

The sliding forces induced by the arch-shaped superstructure on the foundations were contained by providing tie beams and consequently the erection of the four sheds had to be carried out simultaneously. Based on a detailed analysis of the erection time-cycle/day of about 40 m between expansion joints, it was decided to erect a full bay of fertiliser silos in one stretch, deploying the following equipment (Fig.3):

- A rail-mounted travelling scaffold 40 m long in each silo
- A tower crane of 20 t capacity
- 220 t crawler cranes operating from both sides of the silos.

The units were erected on top of the travelling scaffold in sequence and jointed by in-situ concrete. The cables were then stressed and grouted. The simultaneous erection of each 40 m long bay for both silos, including the erection of the prestressed concrete elements, concreting of the longitudinal joints, lowering and the realignment of the travelling scaffold for the next bay, took 14 days during the peak construction period.

For the grain and sulphur silos, it was planned to erect each side unit resting on hinges at the base, supported by a temporary trestle at the top end (Fig.4). The crown unit was erected to rest on top of the half-joint of the side units. The joints were then welded together. The trestle is supplemented by a specially designed travelling gantry in the sulphur silo. The gantry was designed with each leg supporting the side unit vertically. The unbalanced horizontal forces due to the erection of the first side unit are contained by connecting the base of the unit to top of the gantry with a wire tie. Hydraulic jacks are provided at the top to adjust the unit for proper alignment.

The base of the hinge is fixed to the foundation by means of cement mortar. The upper portion rests at the top in a dry joint. The connection is achieved through a rod embedded in the bottom portion. The joint between the hinge and the precast members is realised with cement mortar. After the erection of precast elements, the annular gap between the top and bottom portion of the hinge was filled with a bitumen seal.

Prestressing and grouting

The fertiliser silo arches were prestressed transversely as well as longitudinally. The crown member was separately cross-stressed. The cable ducts were grouted using a Freyssinet J-600 grout pump. The water-cement ratio was restricted to 0.40. Air vents at approximate 6-8m centres were provided along the cable duct. The grout was pumped from the bottom upwards. The low water-cement ratio and high ambient temperature of 35°C initially resulted in low workability of the grout during pumping. This was improved using chilled water for mixing the grout to restrict the grout temperature to below 20°C.

The project, including the design, started in February 1987 and was executed in a record period of two years. The design and construction called for the closest integration of effort between the owner, project consultants, main contractor and sub-contractor.

Owner:	Nhava Sheva Port Trust, Govt. of India.
Project Consultants:	Howe India Pvt. Ltd, New Delhi
Main Contractor:	Klockner-Roxon - Hyundai
Sub-contractor and Designer:	Gammon India Limited, Bombay.