CHAPTER II

2. REVIEW OF LITERATURE

The foundation of a structure transmits the loads from the structure to the underlying soil without causing shear failure of the soil mass or unduly large settlements under the applied loads. Unless these requirements are met the performance of the structure built on the foundation will be adversely affected.

The design of a foundation structure consists mainly of three stages. The first is the selection of the most appropriate and economical foundation for the structure, under the subsoil conditions at the site, so that there is a reasonable factor of safety against failure of the soil under the anticipated loading. The second is the estimation of settlements for the proposed design and the modification of the design so that the calculated settlements do not exceed the permissible total and differential settlements. The third step is to do the structural design of the foundation element proper, for the design loads and the resultant soil reactions.

Shells, in general, are efficient structural forms compared to planar elements. They derive their strength from 'form' rather than 'mass' which enables them to put minimum material to maximum structural advantage. For roofs and floors, shells of various shapes have been adopted with substantial economy in comparison with the conventional reinforced cement concrete slabs.
Inverted brick arch foundations for piers might be considered as the forerunner of the modern shell foundations. Candella (1955) pioneered the construction of roofs and foundations using hyperbolic paraboloid shells in Mexico. The combined 'hypar' footings for a row of columns constructed by Candella was adopted instead of the conventional beam and slab type foundation on a soft clay of low bearing capacity. Subsequently, hyperbolic paraboloid shell footings were used for the construction of the High School Stadium in Sumner, Washington (Anderson, 1960), on a fill resting on a deep deposit of soft mud. They were also used for buildings in the Nonoalco-Tealteldco Project in Mexico City with great economy (Enriquez and Fierro, 1963).

In India, inverted umbrella type hypars have been used for the Shalimar Tar Product Factory, near Calcutta (Bannerjee, 1962), a hypar raft for a single column water tank at Adityapur, Bihar (Bannerjee, 1962 Fig. 2.1) and individual hypar footings for an indoor stadium near Calcutta (Bannerjee, 1976) and for a housing block near Madras (Kaimal, 1967). For a caustic soda factory near Calcutta, hypar footings were constructed over a core of bricks in cement mortar above a concrete mat over timber piles (Bannerjee, 1964) (Fig. 2.2). In Africa, a two storied building at Changme on the mainland at Mombasa (Sondhi and Patel, 1961) was constructed on individual and combined hypar footings resting on a soil with low bearing capacity.

Enriquez and Fierro (1963) reported the use of barrel shell raft for the 128m (420 ft) tall Nonoalco Tower.
on a 27.4m (90 ft) thick soft clay, with shell thickness of 1/50 span in Mexico which resulted in a saving of cost of over 50% in comparison with the conventional foundations. The case of cylindrical shell foundation to support a row of columns for a factory near Calcutta has been reported (ICJ, 1961). The inverted cylindrical shells were cast on stabilized earth set to the correct shape of the shells (Fig.2.3). Brick arches were used to stiffen the shells. The savings in cost was found to be 72% and 55% when compared with the raft and pile foundations respectively.

Conical shell foundations of various types were used for tall television towers at Stuttgart, Dresden, West Berlin, Hamburg, Hannover and Kulpenberg (Ruhe, 1967). The Moscow Tower is provided with an open web conical foundation of extremely slender sections. In a number of antenna towers, the lower part of the shaft is splayed to take the form of a hyperboloid resting on a large diameter foundation ring. Ruhe (1967) concluded that the most efficient type of foundation for a tower shaped structure is a hyperboloid or conical shell with a very wide base bearing on a circular foundation ring. By utilizing the space enclosed by this type of foundation, the economy of the shell may be further increased. Ciesielski (1966) stated that the economy effected in the cost of foundations of a RCC chimney 260m high was 30% by adopting a conical foundation instead of classical slab foundations. Tetior (1966) mentioned that the saving in materials was to the tune of 60% of concrete
and 50% of steel by adopting prestressed concrete shell foundations for tower shaped structures. Leonhardt (1967) advocated the adoption of the flat dish shell proposed by Havelka at least for small towers which can be concreted directly upon the foundation soil (Fig. 2.4). He stated that this would be much more economical than the solid circular slab especially if the stability can be improved by a sufficiently thick covering of earth. In spite of the fact that many hypar shells are being adopted for various projects all over the world, literature on the analysis and performance of models and/or prototype hypar foundations is limited. The studies conducted by Varghese and Kaimal (1967) were one of the first attempts of this kind. They conducted a field test on a fully instrumented hypar shell footing of 135 cm square in plan and 30 cm rise with 5 cm thickness for the shell, resting on a sandy soil. The test revealed the effectiveness of the shape of the footing to stabilize the soil and thus to improve its bearing capacity. The tension cracks first appeared in the edge beam of the shell at about 10 t, at which stage, it was reported that the tensile stresses in the concrete in the edge beam would have exceeded 6.68 kg/cm². After passing through various stages of failure as the load was increased to 26 t, ultimate failure of the hypar shell occurred by punching along the column faces. The tests on model hypar shells were conducted by Kurian and Varghese (1971) on the elastic behaviour of hypar footings on sand. All the models were of cement mortar except one with aluminium. The mortar models
were of 15cm x 15cm size in plan with varying rises and 20cm x 20cm size with different concrete mixes and size of edge beams. The tests on mortar models 15cm x 15cm revealed the increase of stiffness of the shells with increase in their rise. The tests with shell models 20cm x 20cm size shells with and without edge beams revealed the necessity of providing edge beams at least from the point of view of reducing shell deformations and delaying cracking. The studies with aluminium model of 30cm x 30cm size brought out the inadequacy of the membrane theory as applied to hypar footing and it was seen that considerable width of the shell act in conjunction with the edge and ridge beams in sharing the axial forces in them. Further studies on these lines by providing reinforcement in the parallel and diagonal directions in the 20cm x 20cm shells, revealed the usefulness of reinforcement in the shell in its middle plane in directions parallel to the edges, with some extra diagonal steel in the tensile direction preferably below the former. It is reported that the latter besides controlling cracking would have given some additional strength to the footing. Kurian and Varghese, (1972) reported that predominantly two critical zones can be identified in a hypar shell, the central membrane zone and the edge bending zone. This pointed to the necessity of detailing steel throughout the middle plane of the shell, for full membrane action. In addition, extra steel was recommended to be provided in the edge zone, to take up bending there.
Nicholls and Izadi (1968) conducted experimental studies on model hypar footings for the determination of shell strains and soil reaction. These results were compared with the analytically computed values. Model cone footings of plexi-glass sheet also were tested and the results were obtained almost on similar lines. The hypar models were of 30cm x 30cm size and 10cm rise and made of epoxy resin. They were tested on a test bed of sand with soil pressure measurements with capacitance type pressure gauges, vertical displacement measurement with dial indicators and strain measurement with SR-4 strain gauges. Arching action of a uniform sand was observed by pressure cell measurements under cone and hypar model footings. The pressure increase near the perimeter of the cone was barely perceptible and that near the perimeter of the hypar was of the order of one to one half times the pressures measured near the center of the shell, which indicated the necessity of providing larger sections and higher reinforcement for the hypar shell than for the case of uniformly distributed soil reaction. The cost comparison between a conventional square footing and cone footing showed the increasing economy of the latter over the former, with increasing column load and decreasing soil bearing capacity.

A study was conducted by Sharma (1973) on model spherical shell foundation 3m diameter for a water tower which consisted of two spherical shells, one with cavity facing upwards (inner shell) and the other with cavity
facing downwards (outer shell) both the shells were monolithically connected to a ring beam. The centrally applied load was distributed as four column loads on the ring beam through a loading device. Due to the geometry of the outer shell, the loading on it caused hoop tension and thus radial cracks all along the periphery of the shell were observed. All the radial cracks started from the free boundary and propagated almost up to the ring beam at failure. All along the periphery of the ring beam cracks were developed due to the bending moment caused in the ring beam. Because of the geometry of the inner shell, the hoop and meridional forces developed were compressive, therefore, no cracks were observed. It was reported that at the ultimate load, the percentage reduction in the maximum deflection at the free edge of the outer shell was 32% and that the savings of steel requirement was estimated to be 30%, in comparison to a raft foundation of the same capacity and size.

Sharma and Tanwani (1972) presented a simple analysis for solving the problem of a continuous folded plate foundation. The advantage of folded plate over shell foundations was stated to be mainly the elimination of curved surfaces of the latter and reduction in labour cost.

The above studies show that shell foundations are preferable to conventional slab foundations to effect saving of materials of construction and the consequent economy in cost and to impart necessary rigidity for the foundation.
structure on soft soils. However, for the shell foundations, cost of labour per unit volume of concrete will be slightly more than that for slab. But volume of concrete for the former will in general, be less than that required for the latter. The difference in total cost between the two types of foundations decide their relative economy. For comparatively high loads to be transmitted to soft soils, shell foundations have generally proved to be more economical than the ordinary foundations. This is particularly true in countries where the cost of labour is not very high. In the case of developing countries like India, the savings effected in materials, assume great importance since the demand exceeds the production, especially of cement and steel.

The use of hypar shell foundations is in the vogue since the middle of this century. There have been many types of shell foundations designed and constructed throughout the world, resulting in greater economy in cost of construction with efficiency in comparison to alternative planar foundations. Single curvature and double curvature shells are being used as foundation elements. It has now been established that funicular shells are one of the most efficient structural forms for uniform loads. It is therefore reasonable to suggest that funicular shells are ideally suited for taking up uniformly distributed soil reaction.
FIG 2.1 HYPAR FOOTING WITH HEAVY RIBS

FIG 2.2 HYPAR FOOTING WITH BRICK CORE
FIG 23. INVERTED CYLINDRICAL SHELL FOUNDATION

FIG 24. DISH-TYPE SHELL AS PROPOSED BY HAVELKA FOR TOWER FOUNDATIONS