Analysis and Design of Shell Foundation: IS: 9456-1980 Provision

Shaikh Mohd Ahmed[1], Shilpa Kewate[2],

[1]PG Student, Dept of Civil Engg, Saraswati College of Engineering, Kharghar, India, shaikhmoh095@gmail.com
[2]Asst. Prof, Dept of Civil Engg, Saraswati College of Engineering, India, shilpa.kewate@gmail.com

☐**Abstract-** *Shell foundations are economic alternatives to plain shallow foundations in situations involving heavy super structural loads to be transmitted to weaker soils. The development in analysis and design of shell type foundations have led to the understanding that there are more advantages of shell type foundations compared to their conventional footing. In this paper, hypar shell footing were designed and compared with sloped footing. The result were found that the hypar shell footing saves the concrete and steel upto 43.78% and 4.76% respectively.*

.

Key words: Shell Foundation, Sloped Footing, Steel, Concrete.

INTRODUCTION

Shell foundation are considered cost-effective when heavy loads are to be carried by weak foundation soils. Such situations require large-sized foundations because of the low bearing capcity.if we use bending members such as slabs and beams, the bending moments and shears in them will be large and the sections required will also be large. Shells which act mostly in tension or compression will be more efficient and economical in such situations. Even in smaller foundations, the amount of materials that is necessary for a shell to carry a load will be considerably less than that required for bending members such as beams and slabs. However, the labour involved in shell construction (in forming the shell surface, fabricating steel, supervision, etc.) will be more than that is necessary in conventional type of foundations. Thus, in such special situations, one can consider the use of shells as foundations.

However, we must also be aware that arches and many other forms of shells such as inverted barrel shells, folded plates, etc. can also be used as foundation structure. Compared to roofs, these shells when used as foundations will be smaller in spans and also in rise to thickness ratio. We must note that the intensity of loads the shells have to carry as foundation structure will be very much larger than in roofs. The shapes of shells commonly used in civil engineering as shown in figure 2.They are generally classified, in structural engineering as rotational and translational shells. Rotational shells, also called as shells of revolution.

Types of Shells Used in Foundation

The common types of shells used in Civil Engineering practice is given, 1) Domes, 2) Hyberbolic shells, 3) Cylindrical shells, 4) Paraboloidal shells, 5) Conoids(skew shells), 6) Combination of shells.Shell surface are not popular for use as foundations due to such reasons as the difficulty in exactly shaping the surface for the foundation, and casting the concrete.Domes, circular paraboloids are all theoretically possible for foundations. But even though formation of these surfaces for roofs is easy, it is much more difficult for foundation than using conventional foundations such as rafts and piles.however , because of the easiness in construction and forming the casting surface of the cone and the hyperbolic paraboloids, these two shapes have been adopted, to a limited extent, in practical construction. The bureau of indian standards has also published IS 9456 (1980) Code of practice for design and construction of conical and hyperbolic paraboloid type of shell foundations.
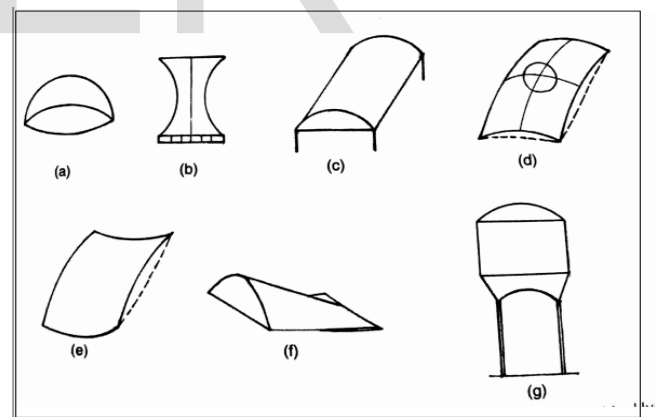
Fig 1 commonly used shells and their classification (a) Dome (b) Hyperboloid (c) Cylindrical shell (d) Hyperbolic paraboloid (f) Conoids (g) Water tank made of a combination of shells.

Scope of using Shells in Foundations

The basic difference between a plain s structural element like a slab and a non-planar structural element like a shell is that, while the former resists transverse loads, including self-weight, in flexure, the same loads induce primarily a direct, in-plane or membrane state of stress in a shell, which may be tension, compression or shear, but all lying in the plane of the shell.

Concrete as a material is most efficient in direct compression least efficient in tension, with the efficiency in bending lying between the two. Thus if a plain roof slab is substituted by a shell and if the geometry and   boundary conditions of the shell are such that the same applied load induces a state of membrane compression, and that too of low magnitude, better material utilization results, which in terms of design means a substantial reduction in thickness.

LITERATURE REVIEW

Dr. Pusadkar Sunil Shaligram, June 2011 , in their paper have conducted experiment on, Triangular shell footing which is used as a strip footing with 60, 90, 120, 150, and 180 (flat footings) peak angles resting on two-layered sand, reinforced with geotextiles.The upper layer of sand is weaker than followed layer. The strip footing was placed on homogeneous sand, reinforced with geotextiles at different depth.The results were indicate that the ultimate bearing capacity increases with decrease in peak angle.

D. Esmaili and N. Hataf, December 2008, in their paper have determined the ultimate load capacities of conical and pyramidal shell foundations on unreinforced andreinforced sand by laboratory model tests and numerical analysis and results were compared with circular and square flat foundations. Both the experimental and numerical studies indicated that , if shell foundation thickness increases, the behavior of the shell foundation on either reinforced and unreinforced sand gets closer to that of flat foundations.

B.B.K Haut, T.A Mohammed, A.A.A Abang Ali and A.A Abdullah, 2007, in their paper two shapes of triangular shells were studied on the performance of the 'upright' triangular and inverted triangular shell using finite element and field model test.Both the finite element analysis and field tests showed that inverted triangular shell had better load carrying capacity compared with the 'upright' triangular shell.

Bujang B.K Haut and Thamer A. Mohammed, 2006, in their Paper have studied on the geotechnical behavior of shell footing using a non- linear finite element analysis with a finite element code, PLAXIS. The shell footing is found to have a better load carrying capacity compared with the conventional slab/flat footing of similar cross sectional area.

Hanna and Abdel-Rahman, 1988, reported experimental journal results on strip shell foundations on sand for plain strain condition. Four shell type footings were investigated with peak angle Ө varying from 60 to 180 . Testing was conducted in a plexiglass tank with dimensions ensuring plain strain conditions. For sand compaction, the drop technique was adopted. Footings were tested at the surface and in buried conditions.

Model footing were subjected to vertical compression load acting on the center by means of a compression machine. The load acting on the footing and corresponding settlements were recorded until failure. The experimental results showed the triangular shell footings had higher bearing capacity and better settlement characteristics than the flat foundation with an equivalent footing width.at a certain load level, the smaller the peak angle of the foundation, the higher the bearing capacity and lower the measured settlement.

THE   HYPERBOLIC   PARABOLOID   SHELL FOUNDATION

The hypar footing made up of four hypar shells with the centre at a higher level than the base. Each hypar consists of the following parts, as shown in fig no-02
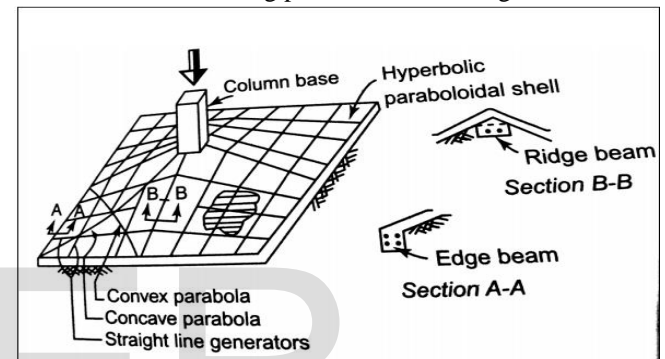
Fig no-02 Hyperbolic Paraboloid individual Shell Footing

- Shell
- Ridge beam (these are the sloping members that support the column)
- Edge beam (these are the beams on the ground along the edges)

MEMBRANE   FORCES   IN   HYPAR FOUNDATION

The unique structural property of the hyperbolic paraboloid (hypar) shell is that under vertical loads, the middle or shell surface of a hypar (with reference to its X- and Y-axes as shown in fig no 03) will be subjected to only uniform shear force of the following magnitude. This is specially true when they are shallow hypar shells.

$$s{=}t{=}\frac{q}{2}\left(\frac{ab}{h}\right) = \frac{q}{2xWarp} \text{ in KN/m}$$

where,

    q=ground pressure in KN/m

   a,b=sides of hypar

    h=rise

  (h/ab)= warp

Direct forces $N_x{=}N_y{=}0$ (for membranes M=0)

In a hypar shell roof where the load acts down, this shear acts from the lowest level to the higher level. Hence in a foundation shell where the ground pressure acts upwards and the column point is above the foundation level, the shear will be acting in the shell from the higher to the lower level as shown in fig no-03
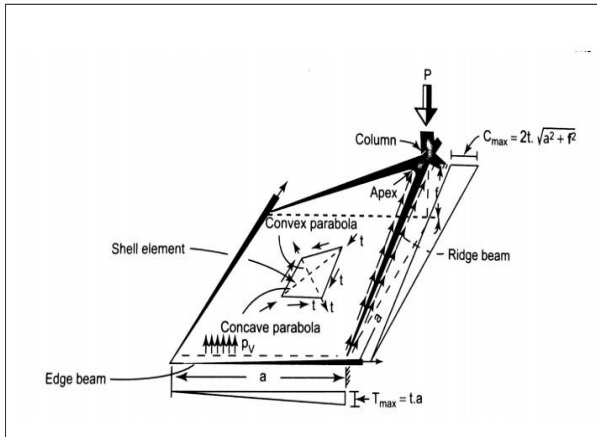

Fig no-03   Membrane Stresses in Hypar Footing

We know that these shears produce equivalent tension and compression along the diagonals. These tensions and compressions can be compared to the forces in two sets of parabolas, each parallel to the diagonals, a concave parabola from the lower to the higher level acting in compression due to load from below and a convex parabola parallel to the other diagonals acting in tension again due to the load from below. The tension in the shell has to be resisted by steel placed in the shell. In fact we provide a mesh of steel as shown in fig no 03 to take care of this tension.

Force in the Ridge Beams and the Edge Beams

- The unique structural property of the hyperbolic paraboloid (hypar) shell is that under vertical loads, the middle or shell surface of a hypar will be subjected to only uniform shear force.
- In a hypar foundation,the forces in the ridge beams boundary members will be acting from the lower to the higher points along the ridge beams so that ridge will be in compression.

- The force in the edge beam will be equal to the sum of the shear forces along the edge of these members and it will obviously be in tension.

- We have tension and compression in the shell, compression in the ridge beam and tension in the edge beams.

MAGNITUDE OF FORCES IN HYPAR SHELL FOOTING

- **Stresses in the shell**

  The shell surface is in pure shear which produce tension and compression as shown in fig.

  Shear=Tension=Compression in shell

  $$s=t=\frac{q}{2}\left(\frac{ab}{h}\right)=\frac{q}{2xWarp}$$

- **Tension in edge beam**

  Max tension=sum of shear along length=a x s

  Where,

  a=Length of edge member or side of shell
  =1/2 the base length of foundation

  Maximum tension occurs at the junction of the edge beam and ridge beam.

- **Compression in ridge beam**

- These compression members should be designed to be sufficient by rigid and should not have more than 5% compression steel in it.

  Compression for each shell=L x s

  Where,

  $$L=\sqrt{a^2+h^2}$$

As two shells from each side of the ridge beam meet along the ridge, the total compression is the sum of forces from the two shells.

$$C=2Ls$$

- Check for column load-it is advisable at this stage to check whether the vertical component of the compressions balances the column load.

  $$C=\frac{PL}{4h}$$

EMPIRICAL DIMENSIONING OF HYPAR FOOTING

The following thumb rules can be used as a rough guide to choose the dimensioning of hypar footings for estimating as well as preliminary planning and design.

1. Rise of shell. The rise of the shell should not be more than the slope at which concrete can be placed and compacted, which is not more than 1 in 1.5 (say about 33.7 degree). In addition, for a hypar to be considered shallow, the slope should not be more than 1 in 2.5 of each of the side of four hypar.generally a maximum slope of 1 in 2 with respect to the side of each hypar can be adopted.

2. The thickness of the shell. The thickness of the shell footing should be more than that used for roofs as we have to meet the needs of cover for foundations. Usually, shells are cast on mud mat with a minimum cover of 50-75mm of $1:1\frac{1}{2}:3$ concrete, and the steel placed at the middle of the thickness will have to be 120-150mm. "A thickness to length ratio" of 1/12-1/16 can be adopted. The shell surface is in pure shear and hence subjected to pure tension and compression.(some recommend a minimum percentage steel of 0.5% to reduce cracking of the shell.)

3. Edge beams. The edge beams at the base are in tension. The thickness of the edge beams is made half the size of the column. Its depth should be about 1/6 the total length of the two hypar(2a) which form the base length. The percentage steel of not more than 5% is recommended. Nominal ties should be also provided. We should remember that this beam is in pure tension.

4. Ridge beams. The four inclined ridge beams are in compression and their vertical component of compression should carry the column. Their breath is made equal to the size of the column and of enough depth to make it a rigid short column member and also to extend into the shell proper. The percentage of steel neend not be more than 5%.

DETAILING OF HYPAR FOOTINGS

1. Junction of the column with shell and ridge beams. The column should properly stand on the top of the ridge beam junction and the column bars should be properly anchored equally into the ridge beams. Also, the shell should be properly joined to the column. Proper fillets should be used at the junction.

2. Junction between edge beam and ridge beam. This junction should be tied together as shown so that the section of maximum tension does not fail prematurely.

3. Corners of the shell. As the two edge beam members that meet at the corners are in tension, there is a resultant tension at the corner and hence a tendency to split along the diagonal.

   The detailing of hypar shells is shown in fig. no 04

PROBLEM STATEMENT

Comparison of hypar shell footing with sloped footing.

- Design a hypar shell footing for a column carrying 1400 KN if the safe bearing capacity of the soil is 150 KN/m^2.

- Design a sloped footing for a square column of 400mmx400mm and intended to carry a load of 1400KN.The safe bearing capacity of the soil is 150 KN/m^2.Assume that grade M25 concrete and Fe 415 steel are used for the construction.

DESIGN OF SHELL FOOTING ACCORDING TO IS 9456-1980.

1. **Find shell dimensions.**
   Adopt a 3.2m square base=9.33m²

2. **Calculate membrane shear on factored load**

   membrane shear =**s**=$\frac{q}{2xWarp}$=329.33KN/m

3. **Design the steel in shell(find area of steel for tension due to shear)**

   Tension=shear=329.33KN/m

   Steel Required=912.14mm²/m
   Percentage of steel=0.76%
   (This steel is more than the minimum 0.12% for shrinkage)
   Provide 12mm bar @120mm giving 942.48mm²/m area.

4. **Check Compression in concrete in the shell.**

   Compression stress=tension=shear=2.74N/m
   This is very much less than 0.4fck=10N/m.

5. **Find tension in edge beam & area of steel in beam.**

   Max tension=shear x length.
   Area of steel required=1459.41mm²
   Provide 4nos of22mm bars=1520.53mm².

Assume width=1/2 size of the column=200mm
Assume depth=300mm

Percentage of steel=2.5%
Good percentage for a beam not more than 5%.also provide nominal ties of 6or 8mm @200mm spacing.

6. **Find compression in ridge beam &provide steel as in column.**

Compression=(shear x length)(2 for two sides)
    =1179.00KN
Compare the above compression as calculated from the column load.

$$\text{Comp. } = \frac{PL}{4h} = 1174.69\text{KN}$$

Make width of beam=that of column
    =400mm

Total beam area=60,000mm^2

As Required=2082.35mm^2
    =3.47%

Provide 4nos rods(3 at the bottom of the rectangle & one at the top of the triangle) of 28mm giving 2463.0mm^2.

Provide ties of 6mm @200mm spacing.

7. **Details special section to avoid premature failure.**

a) Corners at base.
   At corners of the base, provide corner fillets to the width of edge member with nominal ties of 10mm @100mm spacing.

b) Junction between column and ridge beams
   Equal numbers of column steel are continued into ridge beam and lapped with ridge beam steel. The vertical component of the compression in the ridge beam should be more than balance of the column load.

c) Junction of ridge and edge beams.
   The ridge and edge beams by extending steel for a length at least equal to the full development length provide also corner fillet.
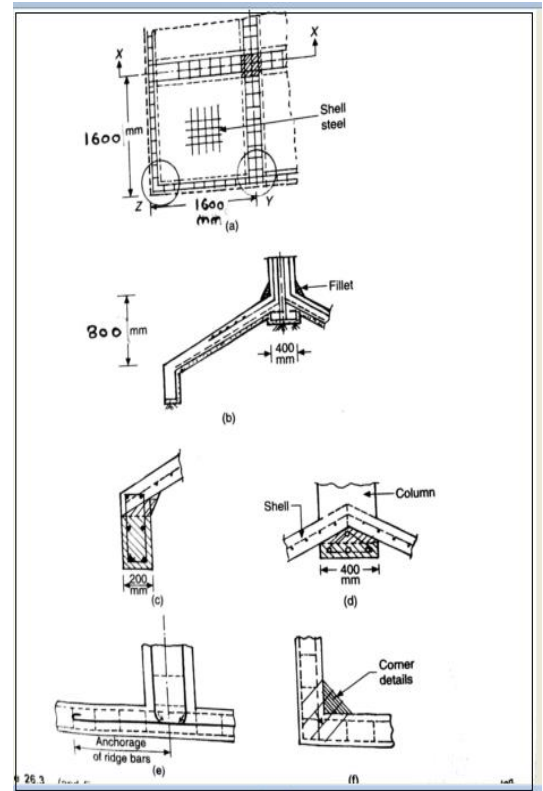
Fig no-04 Detailing of Hypar Shell footings: (a) General arrangement plan,(b) Section X-X, in Figure (a) above (c) Section along edge beam, (d) Detail below column, (e) Detail at junction YY, (f) Detail at corner Z.

RESULT

Comparison between Design of Hypar shell footing and Sloped foooting in following points as given in Table no 01

Table 1:Comaprison between Hypar shell footing and Sloped footing

Sr no	Point of Comparison	Sloped Footing	Hypar Shell Footing	% Save
01	Size of footing	3.4x3.4m	3.2x3.2m	__
02	Volume of Concrete	5.07m^3	2.85m^3	43.78%
03	Area of Steel	10053.08 mm^3	9573.63 mm^3	4.76%

CONCLUSIONS

The Hypar shell footing were designed and compared with sloped footing. The following conclusion can be drawn:

1. The hypar shell footing were found economical than that of conventional footing, and its saves the concrete and steel upto 43.78% and 4.76% respectively.

2. It gives minimum materials consumption over the conventional footing.

3. It gives the greater load capacity and stability over the conventional footing.

REFERENCES

(1) Dr.Pusadkar sunil shaligram(2011). "Behavior Of Triangular Shell Strip Footing on Geo-Reinforced Layered Sand." International Journal of Advanced Technology. IJAET/Vol.II/Issue II/p.192-196.

(2) D.Esmaili and Hataf(2008). "Experimental and Numerical Investigation of Ultimate Load Capacity of Shell Foundation on Reinforced and Unreinforced Sand. Iranian Journal of Science & Technology Vol 32 No B5 pp 491-500.

(3) Huat B. B. K.,Mohammed T. A.,and Abdullah A.A,(2007), "Numerical and Field Study on Triangular Shell Footing for Low Rise Building", International Journal of Engineering and Technology,l. 4- 194-204.

(4) Huat, B.B.K. and Mohammed, T.A. (2006). "Finite Element Study Using FE Code (PLAXIS) on the Geotechnical Behaviour of Shell Footings".Journal of Computer Science. USA: NY. 2(1): 104-108

(5) Abdel-Rahman, M.M, and A.M.Hanna (1988) "Ultimate Bearing Capacity of Triangular Shell Strip Footing on Sand".Journal of Geotechnical Engineering ASCE, 116(2):1851-1863.

(6) IS 9456 – 1980, Code of Practice for Design and Construction of Conical and Hyperbolic Paraboloidal types of Shell Foundations.

(7) Varghese P.C.,(2009) ."Design of Reinforced Concrete Foundations".Published by Ashok K Ghosh, PHI Learning Private .pp 27.