Introduction:

A waffle slab or two-way joist slab is a concrete slab made of reinforced concrete with concrete ribs running in two directions on its underside. The name waffle comes from the grid pattern created by the reinforcing ribs. Waffle slabs are preferred for spans greater than ٤٠ feet (١٢ m), as they are much stronger than flat slabs, flat slabs with drop panels, two-way slabs, one-way slabs, and one-way joist slabs.

A waffle slab is flat on top, while joists create a grid like surface on the bottom. The grid is formed by the removal of molds after the concrete sets. This structure was designed to be more solid when used on longer spans and with heavier loads.[٣] This type of structure, because of its rigidity, is recommended for buildings that require minimal vibration, like laboratories and manufacturing facilities.[٣] It is also used in buildings that require big open spaces, like theatres or train stations.[٢] Waffle slabs are composed by intricate formwork, and may be more expensive than other types of slabs, but depending on the project and the quantity of concrete needed it may be cheaper to build.

There are two types of waffle slab system:

١-One way waffle slab system.
٢-Two way waffle slab system.

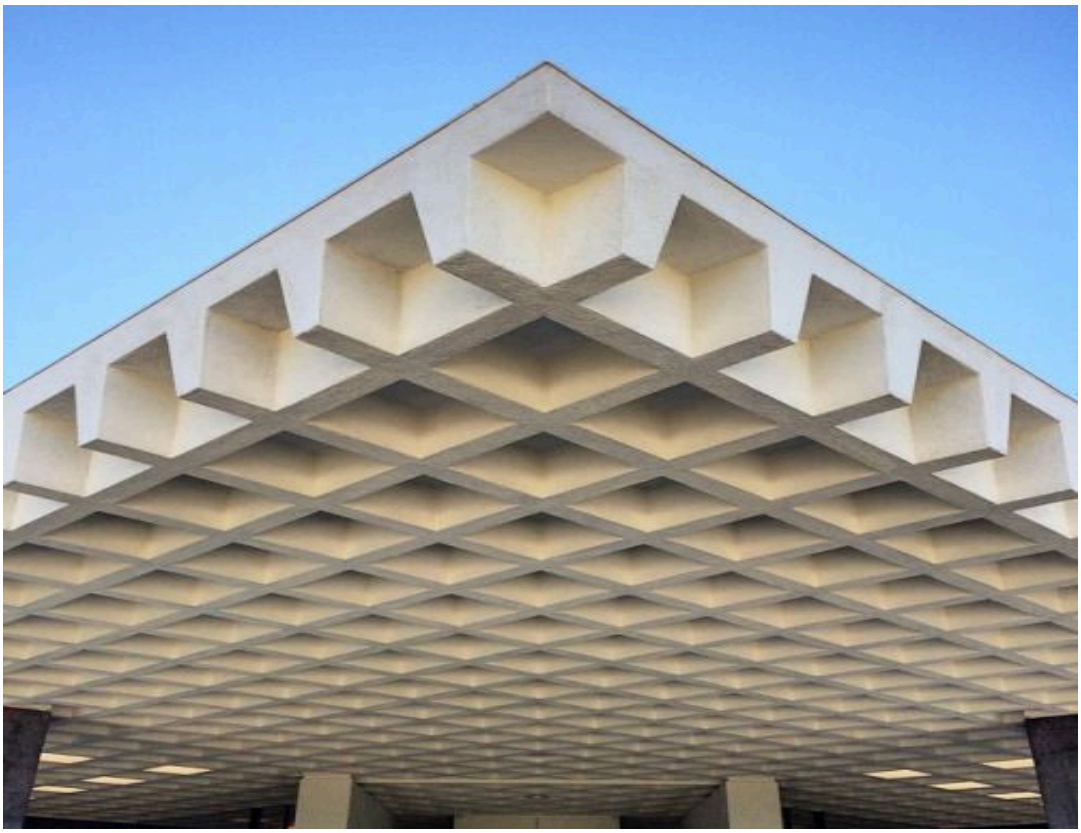


Figure ١

Characteristics of Waffle Slabs.

- Waffle slabs are generally suitable for flat areas.
- Volume of concrete used is very less compared to others.
- The reinforcement in the waffle slab is provided in the form of mesh or individual bars.
- Separate excavation for beams is not required in case of waffle slab.

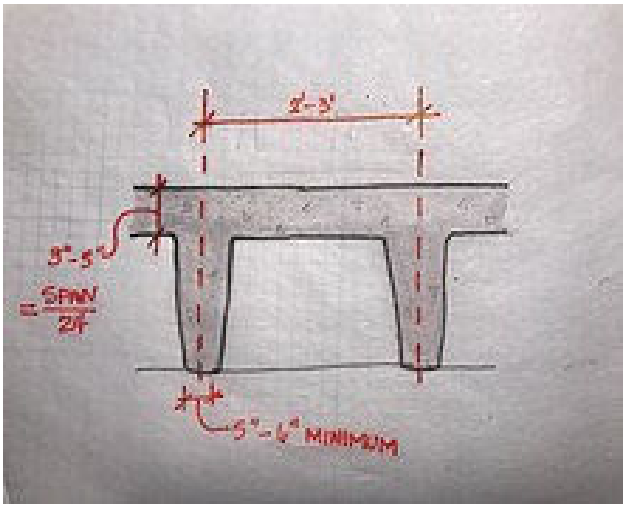
- The bottom surface of slab is looks like waffle which is obtained by using cardboard panels or pods etc.
- The thickness of waffle slab recommended is ٨٥ to ١٠٠ mm while the overall depth of slab is limited to ٣٠٠ to ٦٠٠ mm.
- The width of beams or ribs provided in waffle slab are generally ١١٠ to ٢٠٠ mm.
- Spacing of ribs recommended is ٦٠٠ to ١٥٠٠ mm.
- Reinforced waffle slabs can be constructed for the span up to ١٦ meters while beyond that length prefabricated waffle slab is preferable.
- Waffle slab is good against shrinkage and it is lower than stiffened rafts and footing slabs.
- Waffle slab requires only ٧٠٪ of concrete and ٨٠ % of steel from the concrete and steel used for stiffened raft.

Construction process:

Different guides have been made for architects and engineers to determine various parameters of waffle slabs, primarily the overall thickness and rib dimensions. The following are rules of thumb, which are explained further in the accompanying diagrams:

Diagram shows slab and rib width with rules of thumb formula

- Slab depth is typically ٧٥ mm (٣ in) to ١٣٠ mm (٥ in) thick. As a rule of thumb, the depth should be ١⁄٢٤ of the span.
- The width of the ribs is typically ١٣٠ mm (٥ in) to ١٥٠ mm (٦ in), and ribs usually have steel rod reinforcements.
- The distance between ribs is typically ٩١٥ mm (٣ ft).
- The height of the ribs and beams should be ١⁄٢٥ of the span between columns.
- The width of the solid area around the column should be ١⁄٨ of the span between columns. Its height should be the same as the ribs.



The construction of waffle slabs can be done by three ways as follows.

- In-situ
- Precast
- Prefabricated

In-situ waffle slabs are constructed by pouring concrete in the site or field with proper arrangements. In case of precast waffle slab, slab panels are casted somewhere and they are joined together with proper reinforcement and concrete is filled.

The third case, prefabricated waffle slab is costliest than the other two methods. In this case, reinforcement is provided in the slab panels while casting with some tension. Hence, they do not need internal reinforcement in the site.

To construct a waffle slab in-situ conditions, formwork should be necessary to support the slab. But some special tools are required for the form work in case of waffle slab.

Formwork tools required in the construction of waffle slab are:

- Waffle pods
- Horizontal supports
- Vertical supports
- Wall connectors
- Cube junctions
- Hole plates
- Clits
- Steel bars

Horizontal support and vertical supports are arranged first and they are fixed in position by the connectors. At the edges wall connectors are used to provide connection between wall and slab. The horizontal beam supports are connected by small beam connectors which form square like shape in which pods are going to be placed.

The pods are generally made of plastic and they are available in different sizes and different shapes. Size selection of pod depend upon the requirement and span length. For longer span large number of pods are required. Same size should be used for one complete slab.

Similarly beam connectors and cube junctions are also available in different sizes based on the suitability of pod sizes.

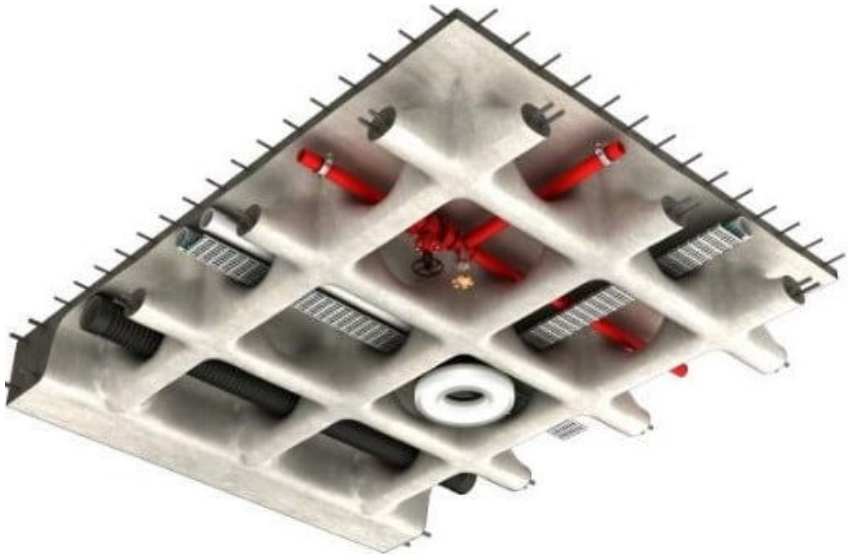
Cube junctions are used to fix the corners of pods with the frame work. After fixing the formwork, reinforcement is placed in the two directions of the slab and then concrete is poured in the gaps which are called as ribs after hardening.

Thin concrete slab is provided on the top and after its hardening pods and frameworks are removed from the bottom. Thus, the waffle like shape appears at the bottom surface.

Advantages:

- Waffle slabs are used for larger span slabs or floors and used when there is limited requirement for number of columns.
- The load carrying capacity of waffle slab is greater than the other types of slabs.
- They provide good structural stability along with aesthetic appearance. Hence, it is constructed for airports, hospitals, temples, churches etc.
- The waffle slab can be made of concrete or wood or steel among those concrete waffle slab is preferred for commercial buildings and other two are preferred for garages, decorative halls etc.
- It has good vibration control capacity because of two directional Reinforcement. So, it is useful for public buildings to control vibrations created by movements of crowd.
- Waffle slabs are lightweight and requires less amount of concrete, hence it is economical.
- Construction of waffle slab is easy and quick with good supervision.
- Concrete and steel volume required is small, hence, light framework is enough for waffle slab.
- Several services like lighting, plumbing pipes, electrical wiring, air conditioning, insulation materials etc. can be provided within the depth of waffle slab by providing holes in the waffle bottom surface. This system is called as Holedeck.

- Better for buildings that require less vibrations – this is managed by the two way joist reinforcements that form the grid.
- Some people find the waffle pattern aesthetically pleasing
- Greater load capacity than traditional one-way slabs
- Forms can be implemented with wood, concrete or steel
- If holes are provided between the ribs, building services can be run through them. One proprietary implementation of this system is called Holedeck.



Disadvantages:

- Greater quantities of formwork materials are needed, which can be very costly
- Waffle slabs are thicker than flat slabs, so the height between each floor must be greater to have enough space for the slab system and other building services
- Waffle slabs are preferred for flat topographical areas not sloped sites
- The floor height should be more hence number of floors are reduced.
- The services provided in the waffle arrangement without proper maintenance may causes damages to the slab.
- Skilled workers are required during its construction.
- They are not suitable for sloped areas. If there is slope area, the area must be leveled with filling or by excavating. For soil filling, good soil should be used.
- They are not suitable against high winds or cyclonic areas because of their light weight.

Design process:

Concrete slabs are created according to three basic designs of which waffle slab is the most innovative. Each slab design is focused on enhancing the structure's strength to weight quotient. All three designs contain a flat top surface with modulated undersides which makes them different from one another. The modulated undersides can be ribbed, corrugated or waffle. Ribbed slabs are used to add foundation strength in one direction while corrugated slabs are used to prevent the foundation from sagging. The concrete waffle slab is used when the objective is to enhance the strength of the foundation in perpendicular directions.

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