7th International Congress on Civil Engineering
ICCE 2006
Civil Eng. Dept., Tarbiat Modares Univ.
May 8-10, 2006, Tehran, Iran

Code: E1265

Methods of Strengthening of the Shallow Foundations

Nima Tafazzoli, MSc. of Geotechnical Engineering, nimatafazzoli@yahoo.com
College of Civil Engineering, Iran University of Science and Technology

Behrouz Shafei, MSc. of Structural Engineering, Behrouz.Shafei@gmail.com
School of Civil Engineering, University of Tehran

Abstract
Strengthening of the foundations might be needed due to the alterations in serviceability of the buildings; these changes will directly affect the amount of gravity loads of the structure. Existence of some errors in calculating the loads, especially lateral forces such as earthquake, during the designation procedure is another important parameter that makes the strengthening necessary. In most cases, process of strengthening of the foundations is done under inconvenient conditions. Strengthening requires the use of special technologies and also organization of construction materials. Execution of construction work under constrained conditions hampers the use of mechanized equipment and complicates the supply of necessary construction materials.
Problems of strengthening of foundations are practically untouched in the standard specifications and corresponding reference materials which are in present-day use. The current paper describes some of the general methods of strengthening of the shallow foundations which are used widely and also have a great influence on increasing the force bearing capacity of the building. Obviously, selecting the appropriate method of strengthening will be done by consideration of the site conditions.
Keywords: Strengthening, Shallow Foundation, Concrete Jacket, Pile, Grouting

1- Introduction

Loads on foundations, increase during the process of reconstruction of engineering equipment, replacement of obsolete machinery and individual structures, extension of the span of bays, provision of underground space for production etc. A characteristic feature of the process of strengthening the foundations, is needed to carry it out under inconvenient conditions. This requires the use of special technology and organization of

construction materials. Execution of construction work under constrained conditions hampers the use of mechanized equipment and complicates the supply of necessary construction materials which in the final analysis leads to higher man-hours and costs for the work of strengthening of the foundations.

Strengthening implies any changes in the structure or dimensions of existing foundations for the purpose of adapting them for service under alter conditions. Strengthening is associated with restoration or replacement of their obsolescent or physically broken-down construction elements as well as with increase in load on foundations. Sometimes seismic strengthening of foundations is required due to earthquake loads which may directly cause some problems for foundation or in addition to the other loads uplifts may be founded.

Foundations are subject to physical wear with passage of time. It is not unusual to come across instances of foundations breaking down, much earlier than their designated period of service. For instance, when a foundation is exposed to the action of corrosive groundwater, its protective concrete layer is destroyed and its reinforcement thereby exposed to corrosion. Under such conditions, a foundation may lose its load-bearing capacity to such an extent that strengthening it becomes an inevitable necessity.

2- General Methods of Strengthening the Shallow Foundations

Selection of the method of strengthening of shallow foundations, depends on the reasons necessitating such reinforcement, constructional features of existing foundations and engineering geological conditions of the area on which the structure is located.

It is well known that designs for strengthening foundations are generally more difficult to implement than those for the construction of new buildings. This is explained by the fact that in each case of strengthening foundations one has to take into consideration the service conditions of structure, constraints on execution of repair work and a variety of deformations in the buildings and structures.

Methods of strengthening the shallow foundations presently in use, may be classified according to the type of construction method and mode of its execution as below :

1) strengthening foundation slabs by cementing voids develop at joints
2) Partial replacement of foundation slab when damage to foundation material excessive
3) Installation of reinforcing bands or jackets without widening base of foundation
4) Widening base of foundation (when bearing load on foundation increases)
5) Strengthening by driven piles (when load significantly increased and underlying soils are firm)
6) Strengthening by cast-in-situ piles (when increases in load significant and thick layer of weak soils lies at base and also conditions of work for reconstruction difficult)
7) Transfer of part of load onto additional foundation (under complex combinations of loads and unusual conditions under which reconstruction is carried out)
8) Conversion of columnar foundations to strip foundations and strip foundations to slabs (when deformations at base of foundations are highly uneven and also when a change in loading occurs, in this method installation of additional equipment are necessary)

3- Strengthening of Foundations with Jackets

Foundations of industrial and residential buildings constructed during the first half of the twentieth century, were usually built with stones, rubble masonry and baked bricks. Over course of time such foundation materials lose their strength and become susceptible to damage due to the adverse effects of groundwater, corrosive media, temperature and other factors. In this case the material at the joints often becomes damaged.

Cement grouting is used to restore and strength of the foundation. This is done usually by forcing cement slurry of 1:1 to 1:2 consistency into the cavities of the foundation through injection tubes under a pressure of 0.2-1 MPa. Sometimes jackets used for strengthening, which may be made from coarse sand mortar. This can also be done by pneumatic spraying or pouring concrete into reinforcement casings. If grouting is too difficult, the foundation may be strengthened by concrete jackets laid over entire height of the foundation or some portion of it (Figure 1). Sometimes these jackets are constructed with injection tubes already installed in them to facilitate subsequent grouting. In such cases the jackets prevent leakage of slurry from the foundation and ingress into the soil.

Also when cracks appear in the lower part of foundations, they are strengthened by placing longitudinal concrete beams below them (Figure 2). Further the entire foundation is encased in a concrete jacket monolithic with the foundation beams. Depending on the rate at which load increases, the foundation may be strengthened either as a continuous mass or at discrete intervals. The width at the base of the foundation increases during its strengthening, while the depth at which it lies remains unaltered.

Strengthening foundations by installing jackets can be achieved either without increase in bearing area at the base or increasing it, whenever the soil has inadequate bearing capacity, the foundation is partially damaged or the load on the foundation increases significantly during reconstruction. In figure (3.a), the foundation strengthened by encasing the upper portion above the slabs within concrete jackets can be seen. This made it possible to ensure a more uniform loading of the slab. In Figure (3.b), strengthening by concrete jackets with increasing the width of the foundation can be seen. Also in Figure 4, a method of strengthening the columnar foundation can be seen.

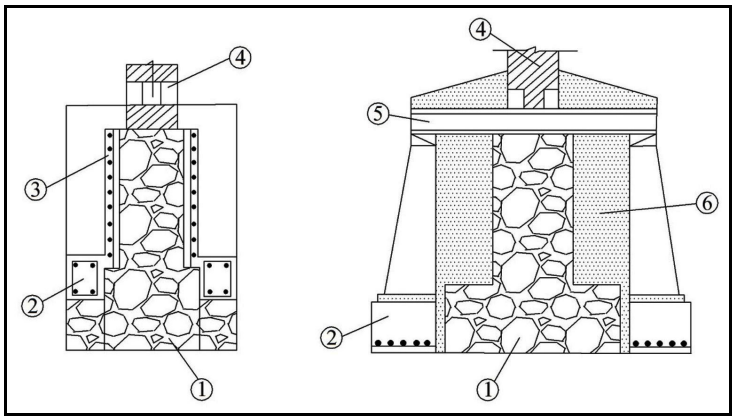

Figure 1: *Method of strengthening of the strip foundation; 1- foundation; 2- concrete beam; 3- jacket; 4- wall of building; 5- steel crossbeam; 6- monolithic concrete [1]*

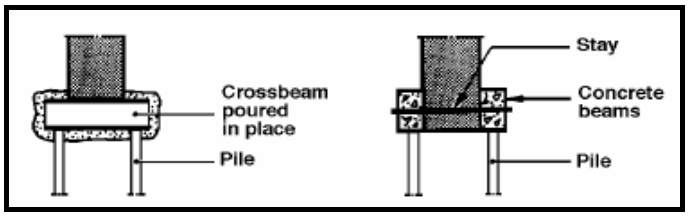

Figure 2: *Load transfer via longitudinal and cross beams [3]*

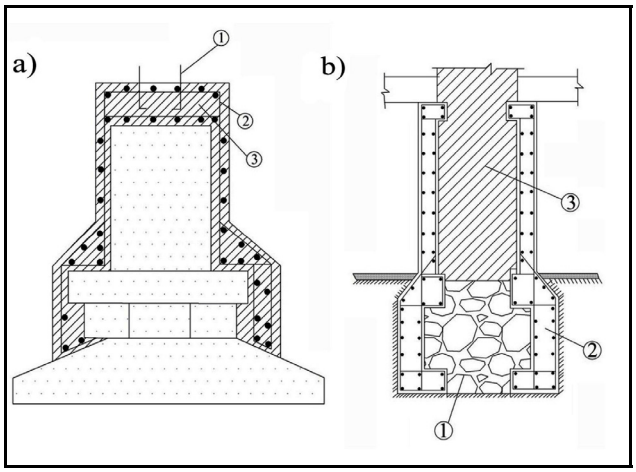

Figure 3: *a) Method of strengthening precast foundation by a concrete jacket*
1- anchor bolts; 2- welded reinforcement cage; 3- jacket
b) Method of strengthening strip foundation
1- foundation; 2- strengthening jacket; 3- basement wall [1]

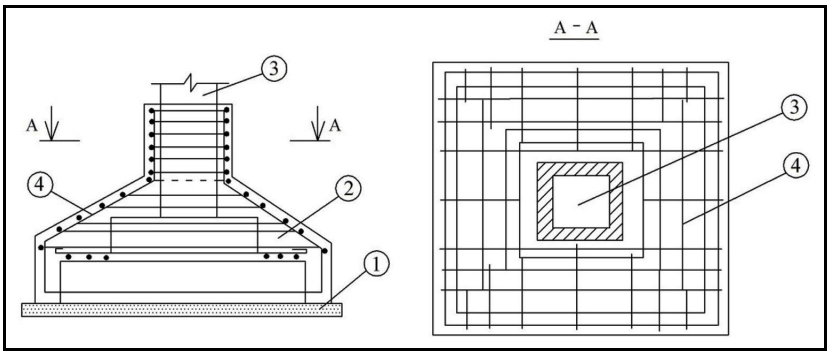

Figure 4: *Method of strengthening columnar foundation*
1- foundation; 2- strengthening jacket; 3- column; 4- reinforcement [1]

When jackets are installed to strengthen the foundation, it is not always possible to assure that the bond between the new concrete and that existing earlier would guarantee a completely solid bond between the concrete of the jacket and the existing foundation. In a number of cases, it has been necessary to remove the entire outer layer of the existing concrete and to weld reinforcement stubs, crossbeams, anchors and other elements. Fresh cement is plastered on a clean roughened wet surface of the existing foundation, taking care that the concrete mix is well compacted.

4- Strengthening by Underpinning and Enlarging the base of the foundations

Strengthening shallow foundations may be carried out by under pinning and enlarging their base, as well as increasing their depth by underpinning with additional structural elements below the existing foundations. Strengthening foundations without markedly increasing their depth is done by underpinning them with a concrete slab below the base of the existing foundation. The soil under foundation is excavated at intervals of 1-2 m and a solid concrete slab is laid in-situ or a precast concrete slab is installed in the excavated pit (Figure 5).

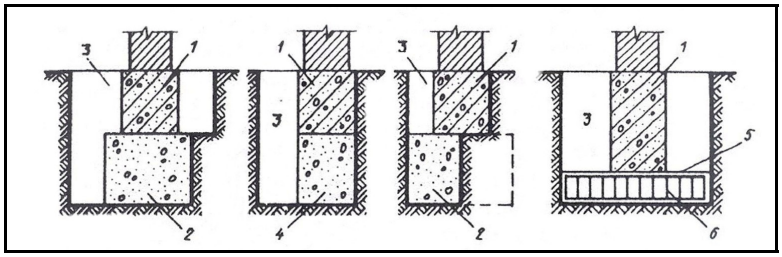

Figure 5: *Different methods of underpinning and enlarging the foundations*
1- foundation; 2- column; 3- pit; 4- wall; 5- slab; 6- reinforcement cage [1]

After compressing the soil under foundation with jacks, the space between the slab and the base of the existing foundation is filled with concrete that is thoroughly consolidated by agitating it with vibrators. In some cases, it is desirable to partially reduce the load from the spans and walls during underpinning of foundations by installing temporary supports or metallic wall beams to relieve the load.

5- Strengthening of the Foundations by Converting the Type of Them

In strengthening columnar foundations, they may sometimes be rebuilt as strip foundations and strip foundations may be converted to slabs. Such cases arise when the soil under foundation has undergone significant uneven deformation, magnitude of load and working conditions of the foundations change, the constructional layout of the building or structure is altered, the rigidity of the building needs to be considerably increased and several other reasons. A concrete wall in the form of a connecting slab is installed between existing columns to convert a columnar foundation to a strip foundation (Figure 6).

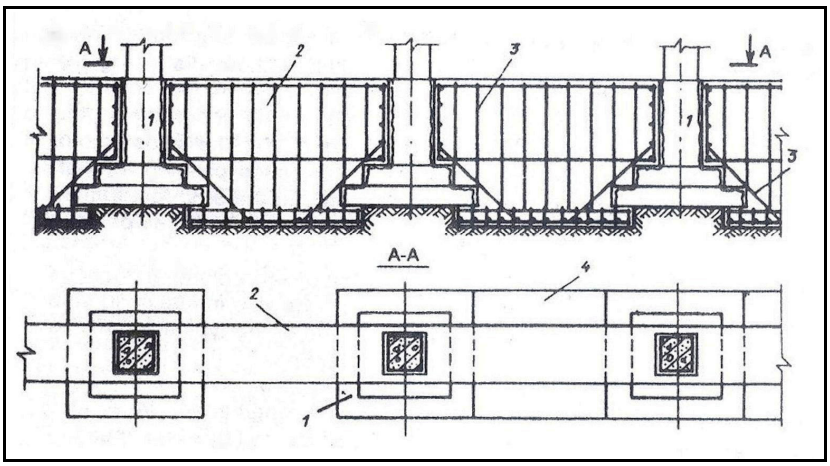

Figure 6: *Conversion of columnar foundation to strip foundation [1]*

1- columnar foundation; 2- concrete wall; 3- reinforcement cage; 4- enlarged portion

To ensure better contact between the connecting slab and the existing foundation, notches and serrations are cut in the existing foundation and their reinforcements exposed in order to weld them to those of the connecting slab. Also the footing of the column is enveloped by a concrete jacket. The lower part of the connecting slab may be made extra wide in order to increase its load-bearing capacity. Conversion of strip foundations to slabs is done by underpinning the ends of the slab below the strip footing (Figure 7).

The slabs adjoining the strip footing are joined to each other by bands passing through openings made through the lower part of the wall on the strip foundation. The slabs are interconnected at a distance of 3-4 m by concrete ties passing below the base of the strip footings. In figure 8 strengthening of the foundations via jacket and enlarging the dimensions of the foundations, can be seen.

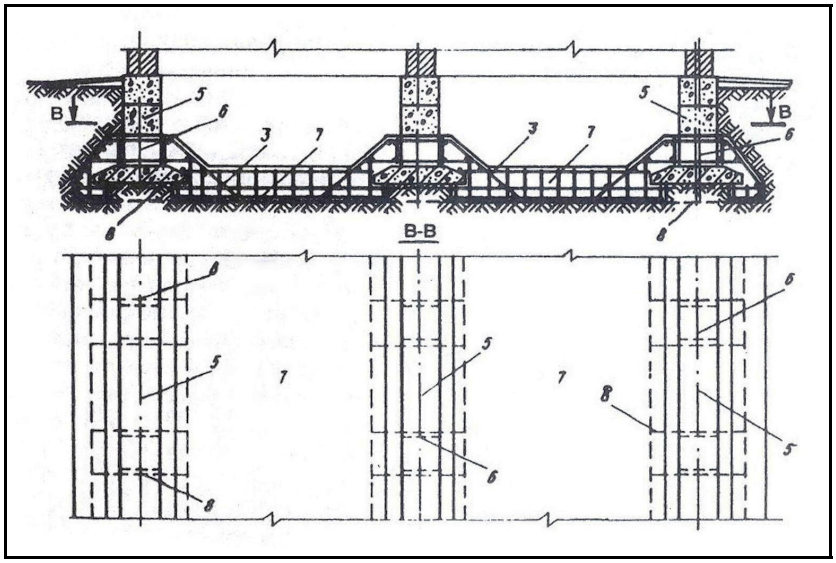

Figure 7: *Conversion of strip foundation to slab*
3- reinforcement cage; 5- strip foundation; 6- opening in strip foundation; 7- underpinning slab; 8- concrete ties [1]

Figure 8: *Expose the reinforcement of the existing foundation to weld to the jacket (left), Excavation around the existing foundation and setup new reinforcement rods to enlarge the dimensions of the foundation (right)*

6- Strengthening of the Foundations by Piles

Piles are used in extremely complicated cases of strengthening shallow foundations, wherein the load of the building has to be transferred onto firm soils lying at a greater depth, specially when groundwater are present at a high level. Strip foundations may be strengthened by installing carrier piles on each side or on one side only in one or two rows. Piles may be placed on the two opposite sides at the base of the foundation or around it, for reseating columnar foundations.

The length of the pile is determined on the basis of soil properties, cross-sectional area of the piles and load on the foundation. In the case of high loads, it sometimes becomes necessary to drive in piles in two rows. The piles are placed below the foundation if the latter is wide enough or else on either side of the foundation and sometimes below a cantilever extension as shown in figure 9.

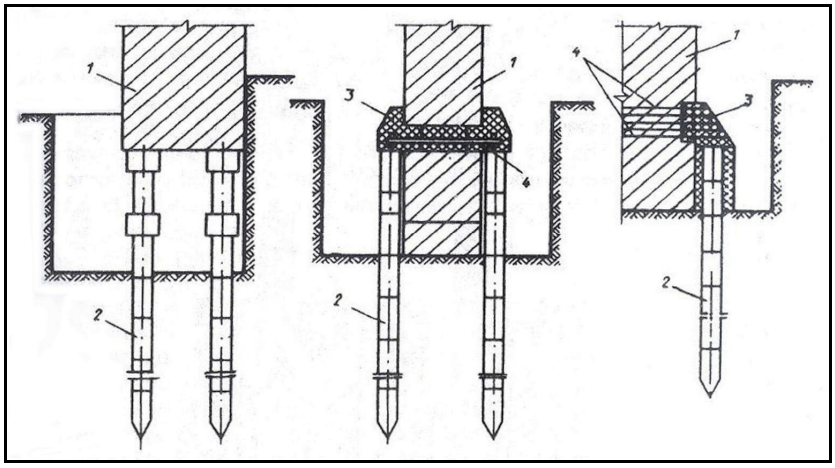

Figure 9: *Different methods of strengthening foundations by piles*
1- foundation; 2- piles; 3- concrete beams; 4- ties [1]

Aperture and channels are cut in the existing foundation to attach the piles to it and the projecting beams fastened with steel ties. It is preferable to install continuous longitudinal beams, since they distribute the reactions from the piles over a considerable length and help to increase the rigidity of the foundation in a longitudinal direction.

Also in some projects inclined piles may be used for strengthening the foundations which is useful to resist against the lateral forces such as earthquake.

7- Special Features of Strengthening of the Foundations

Strengthening of shallow foundations must be done with almost care under the direct supervision of the repair organization. The task of strengthening should be completed in a short period utilizing mechanized method to the maximum and prefabricated constructions such that high man-hour output is assured. Concreting work is carried out over small sections in such a way that the next section of concreting begins only after the section concreted earlier attains the desired strength. When new concrete is laid alongside an existing section, a joint is formed at the contact surface. Concrete strengthening elements exposed to corrosive media are made from dense waterproof concrete with a water to cement ratio of 0.55. The density of the concrete is selected on the basis of the degree of corrosiveness of the surrounding media. High-grade Portland cement is used as building materials. The chemical composition of the

cement and the density and strength of coarse and fine aggregates have to satisfy stringent specifications. Reinforcement rods, rigid reinforcements, foundation bolts etc. must be inspected before the foundations are concreted.

The volume of concreting work during reconstruction of plants which are in normal production increases by 1.5-2 times since traditional methods of delivering concrete mix by means of cranes and concrete placers cannot be used in most cases, then additional materials can be used in concrete to reduce the strengthening time.

Before commencing the work of strengthening the foundations of multi-storey buildings, it is advisable to transfer the load from the ceilings onto temporary vertical supports (Figure 10). Temporary supports are first installed in the basement or on the ground floor, followed by erection of similar supports on the ceiling. Then wooden or steel beams laid transverse to the direction of the beams supporting the wall serve as the base for the supports. The supporting structures are placed 1.5-2 m from the walls in order to transfer the load on the temporary supports made in the soil for carrying out the work of strengthening the foundations and soils under foundation.

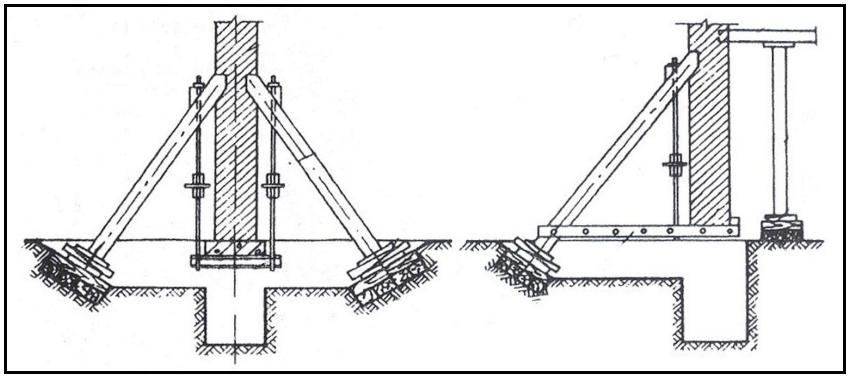

Figure 10: *Installing supports during strengthening of foundations [1]*

8- Conclusions

Strengthening of the foundations might be needed due to the alterations in serviceability of the buildings; these changes will directly affect the amount of gravity loads of the structure. Existence of some errors in calculating the loads, especially lateral forces such as earthquake, during the designation procedure is another important parameter that makes the strengthening necessary. In most cases, process of strengthening of the foundations is done under inconvenient conditions. Strengthening requires the use of special technologies and also organization of construction materials.

Strengthening implies any changes in the structure or dimensions of existing foundations for the purpose of adapting them for service under alter conditions. Selection of the method of strengthening of shallow foundations, depends on the reasons necessitating such reinforcement, constructional features of existing foundations and engineering geological conditions of the area on which the structure is located.

Strengthening the shallow foundations, may be done by cementing voids develop at joints, partial replacement of foundation slab, installation of reinforcing bands or jackets, widening base of foundation, strengthening by driven piles, strengthening by cast-in-situ piles, transferring load onto additional foundation, conversion of columnar foundations to strip foundations and strip foundations to slabs.

9- References

[1] L.K.Ginzburg, V.B.Shvets and V.I.Feklin, *Reinforcement and Reconstruction of Foundations*, Balkema, 1996
[2] M.J.Tomlinson and R.Boorman, *Foundation Design and Construction,* Longman Publication Group, 1995
[3] *Foundation Retrofit and Rehabilitation*, Alaska Building Research Series, 2001
[4] Robert W.Day, *Geotechnical and Foundation Engineering: Design and Construction*, McGraw-Hill, 1999
[5] M.Saiid Saiidi, David Sanders and Suresh Acharya, Seismic Retrofit of Spread footings supporting bridge columns with short dowels, *Construction and Building Materials*, 2001
[6] Marcel Dekker, Wind and Earthquake Resistant Buildings, John A.Martin & Associates, 2005