Consolidation of masonry foundation.

IS IT:

- [ ] *Product*
- [X] *Technology*
- [ ] *Equipment*

APPLICABLE FOR:

- [X] *Restoration*
- [X] *Rehabilitation*
- [ ] *New Construction*

APPLICABLE ON:

- [X] *1. Foundations and underground structures*
- [ ] *2. Vertical structures*
- [ ] *3. Horizontal structures and vertical connections*
- [ ] *4. Roof and terraces*
- [ ] *5. Façade and building envelope*
- [ ] *6. Finishes and completion elements*
- [ ] *7. Integrated services*
- [ ] *8. General strategies for building recovery*

Related companies: *No companies; university research; structural study.*

DESCRIPTION

This intervention is a traditional methodology aimed at structural consolidation for the underground structures and masonry foundations. It is widely used in many rehabilitation/restoration cases.

The aim is strengthening the bottom masonry by extending the structure until reaching some consistent soil layers; at the same time increasing the contact area at the base in order to reduce the unit bearing load.

Like every structural intervention related to foundations, it requires some specific precautions to avoid instability and problems for the elevated structures.

It can be carried out by excavating in front of the foundations to be strengthened, using different and multiple excavation consolidation techniques.

In addition to the anthropogenic factors - such as an uncertain construction realization, an increase of structural bearing loads, a change of building use, incorrect disposal of rainwater, a change in the conditions of equilibrium at the ground level for the surrounding buildings. The modified features of the initial conditions of the masonry foundations are also caused by natural and external factors, including the raising or lowering of the aquifer or fault movements.

These phenomena have a negative impact on the structural stability of the foundations, giving rise to subsidence which, especially when differential, generate instability occurring with rotations and cracks in the above masonry. In case of cracking pattern, a careful analysis must be done as it can provide useful information on the phenomena affecting the seabed structures and the resistant soil.

WHY TO USE

The aim is strengthening the foundations' support both longitudinally and in height, distributing more evenly the load-bearing load.

It must always be considered the most traditional and safe techniques in order to guarantee to the foundations a more consistent and, therefore, more load-bearing support onto a portion of the foundation ground.

It is a non-invasive technique, which guarantees low vibrations, structural reinforcement and, above all, the certainty and safety of the expected result.

Among the most common and traditional interventions the following are reported:

- The lowering of the foundation plane towards a resistant soil layer which consists in the construction of a new foundation positioned at a lower altitude, thus transferring the load to a deeper laying surface, that is considered more suitable, with better mechanical characteristics and/or less compliant.

This structural intervention requires a prior verification of the bearing capacity of the soil, considering several factors such as the vertical structure, the ground features, and the environmental conditions of the location.

- The widening of the foundation base, which consists in the extension of the support surface by means of beam curbs made adjacent to the foundation wall.

This intervention is suggested when the foundations are insufficient in size for a suitable transmission of the overlying load.

By increasing the surface there is a better load distribution onto the ground. This intervention must be done allowing the original and the new reinforcement structures to collaborate together and evenly distribute the loads over a larger portion of soil.

HOW TO USE AND APPLY

The intervention in the foundation requires preliminary geological investigations to verify the mechanical characteristics that are such as to withstand the loads transmitted by the vertical structure more effectively than in the previous situation.

For continuous masonry foundations the most common interventions are:

- making a new foundation at a lower altitude, reaching a more resistant layer of soil;
- widening the base of foundation, aimed at extending the laying surface of the foundation and distributing the loads over a larger portion of the soil.

LOWERING THE FOUNDATION PLANE

To avoid collapses, the structural intervention is always carried out involving limited parts of foundation masonry and realizing partial construction sites and the entire vertical structure must be lightened and propped up as possible.

The sub-construction sites must be compact (about 1,5 mt) and positioned in points sufficiently distant from each other, never adjacent. During the design phase, the parts of the foundation intervention and the sequence of execution are identified, in order to limit the imbalances of the vertical structure and the excessive loading of the soil in the areas adjacent to the consolidation intervention.

The forces stabilize once the entire intervention has been completed when the underlay new foundation will be entirely in place.

Then it can be possible to proceed by digging alongside the foundation until the new bottom foundation plane is reached. It depends on the masonry thickness and the site's accessibility. It is carried out on one side only or on both sides (on the external side or on both sides; outer sides/whole). The walls of the excavation must be properly reinforced going down in depth.

The excavation below the existing foundation is carried out by placing appropriate supports and supporting beams between the intrados of the masonry and the bottom of the excavation to avoid the relaxation of the upper structure. Subsequently, the foundation masonry is carried out (see the voice “technical procedure”).

INTERVENTION OF FOUNDATION BASE ENLARGEMENT

The widening of the foundation base can take place on both sides of the foundation, or on one side only.

The enlargement takes place by creating reinforced concrete beam-curbs side by side and collaborating with the existing foundation. If it is possible to operate on both the sides of the foundation, the beam curbs are double; it will be single in the event that, i.e., the work is done in underground space or there are boundary and accessibility problems.

In the case of a continuous masonry foundation, the beam-curbs are made along the entire wall perimeter. In the case of plinths, the beam-curbs will be around the single plinth.

The transversal connection between the beam-curbs and the foundation can be realized in different ways such as: connection with cross beams made with metal profiles, with squat concrete beams or with threaded steel bars, connected to lateral steel plates, post-tensioned after the curing of the beam-curbs.

BOTTOM LEVEL LOWERING OF FOUNDATION INTERVENTION - OPERATIONAL PHASES

1. shore the vertical structures in elevation;
2. identify the work building sites (Fig. 1) and number in succession corresponding to non-contiguous sites, distinguishing between those corresponding to passageways (empty sites) and to full ones (full sites);
3. if it is possible, excavate on both sides for a wall thickness at least 1,50 m or on one side only for lesser thickness; these excavations must be carried up to the level of the laying surface of the existing foundation, providing for the reinforcement of the walls of the excavation (Fig. 2);
4. check the conditions of the foundation and, if necessary, intervene with consolidation works such as injections of cement mortar, etc.
5. completion of the excavation under the existing foundation for the entire length of the sub-construction foundation building site, inserting two or more supporting beams between the intrados of the foundation and the bottom of the excavation;
6. creation of the solid brick sub-foundation (see Fig. 3) of the necessary dimensions, leaving the indispensable grips for the subsequent contiguous sections to be built.

It is possible to do the foundation work in reinforced concrete also as follows: casting a layer of lean concrete, positioning the reinforcement and carpentry and, finally, casting the concrete along the entire width of the excavation (Fig. 4).

7. Clamping, contrast and implementation of the coercion of the new masonry with the existing one, using hardwood elements wedged under pressure. Remove after 3-4 days and replace with larger wedges to compensate for the lowering of the new masonry. Afterwards, extract the wedges and the solid bricks, forced into the masonry, placed in the last row, thus completing the underlay;
8. Progression of the other foundation sub-construction sites upon completion of the first construction site;

9. Repetition of the same phases (from 3 to 8) for all the other sites, following the numbering attributed to them.

INTERVENTION TO WIDEN THE FOUNDATION BASE - OPERATIONAL PHASES

1. excavation around the foundation, then close to the wall, up to the foundation surface to observe its condition and dimensions;
2. execution of the reinforced concrete beam-curbs: positioning of the brackets and steel rods; the foundation formworks are placed close to the existing foundation (Fig. 5); casting of concrete.
3. connection of the reinforced concrete beam-curbs to each other and to the existing foundation. Exploit crosspieces wh consisting of: galvanized metal profiles embedded in a mortar aimed at protection, squat concrete beams or stainless-steel threaded rods (with a diameter of at least 20 mm), drowned in the existing foundation with mortar mixed with resin and connected to the beam-curbs in contrast with external side plates and then tensioned with a dynamometer wrench (Fig. 6).

N.B.: The connection with squat beams is the least recommended as it is more invasive and less compatible with masonry foundations.

TECHNICAL CHARACTERISTICS

Both the consolidation interventions can be carried out for the solid brick masonry or the reinforced concrete.

- All sub-foundation interventions must be carried out with all possible cautions to avoid affecting the original static/structural balance needing consolidation, nor the one of possible adjacent buildings;
- If the masonry of the existing foundation appears weak and not homogeneous, before intervening, it will be necessary to provide a general consolidation (eg: injections of mixtures based on anti-shrinkage hydraulic mortars or reinforced seams or substructures, etc.)
- If the foundation or its enlargement is done with brick masonry, there are no compatibility problems: pay attention to avoid percussion on the masonry that could cause damage to the above structures and check the progressive commissioning of the new structure in respect to the existing one.
- When using solid bricks, it is good practice limiting <1 cm the mortar thickness among the joints, in order to make the settling of the wall structure negligible.
- Whenever possible, it is best to avoid working with only one beam-curb on one side to avoid eccentric loads.
- If the vertical masonry appears not homogeneous, previously is necessary securing, shoring up and consolidating the vertical structures and then work on the foundation.

RECOMMENDATIONS AND OTHER INFORMATION

This consolidation intervention is very complex and dangerous, as there is a high risk of collapses during the excavation.

Consequently, it is important to analyze the past structural interventions, the constructive technology and materials used, materials' decay and deterioration, the crack pattern, and - above all - the consistency of the foundation and the nature of the soil on which they insist.

EXAMPLES

EXTENSION OF THE BOTTOM LEVEL FOUNDATION OF THE D'ESTE CASTLE OF ARQUÀ POLESINE, IN ROVIGO (ITALY).

The building is a medieval fortification located in the center of the town of Arquà Polesine, a town in the province of Rovigo. Nowadays, only the central part of the original nucleus remains, being partially used as a municipal house, and a three floors crenellated tower.

The castle was the object of a general structural intervention of consolidation. Regarding the foundations, the laying surface was widened by lateral confinement of the masonry (reinforced concrete plinths) around the masonry and connection between the original masonry by means of steel profiles.

Fig.1-2: Execution of reinforced concrete curbs. Intervention carried out in the d'Este Castle of Arquà Polesine, Rovigo.

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FOUNDATION CONSOLIDATION INTERVENTION IN THE SAN FRANCESCO MUSEUM IN MONTEFALCO, PERUGIA, ITALY.

The museum-complex of San Francesco is known for the important testimony of a Renaissance painting of the 15th-16th centuries. It is composed by the Church of San Francesco, the Civic Art Gallery, an Archaeological section, the friars' cellars, and spaces for temporary exhibitions.

The project for the construction of a new museum arrangement was carried out in 1990, with the acquisition and restoration of some former convent rooms. The adaptation and restoration work also involved the ground foundation system of the complex, building a solid brick underlay, which lowered the foundation plane towards a layer of soil showing a greater mechanical resistance.

Fig.3-4: State of the foundation masonry before the consolidation intervention.

Fig.5-6: Realization of sub-building consolidation works.

Fig.7-8: Intermediate phases of consolidation work.

Fig.9-10: Final phase of consolidation work.

***The images illustrate the operational phases carried out in the San Francesco Museum Complex in Montefalco, Perugia.*
Source: ©Donà C. (edited by), De Maria A, Borri A, et. al., Manual of historical masonry, DEI Tipografia del Genio Civile, Rome, 2011.

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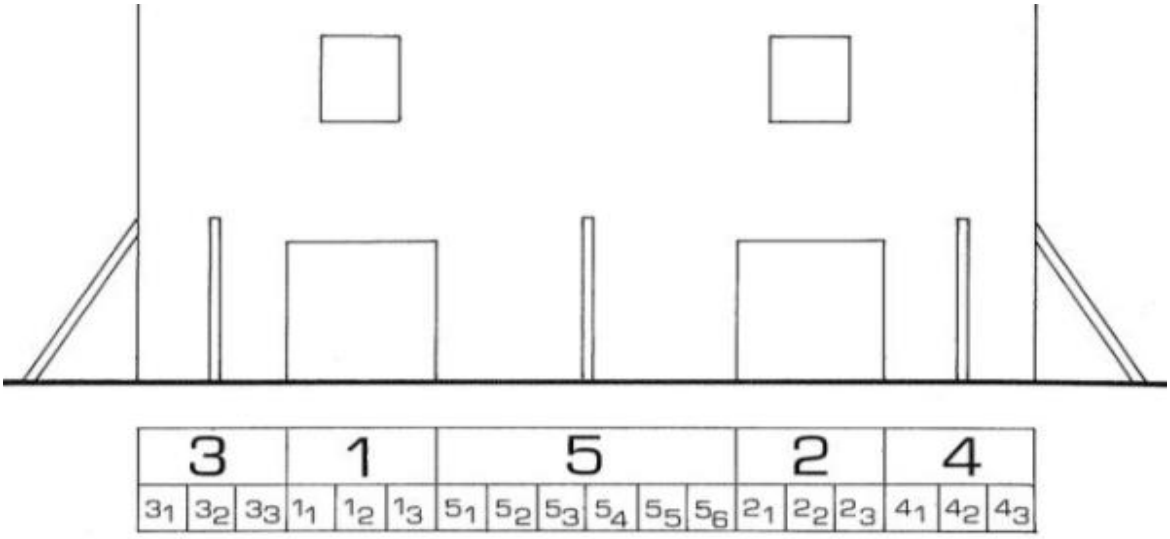

Fig.11: Scheme of division of works in construction sites and sub-construction sites.

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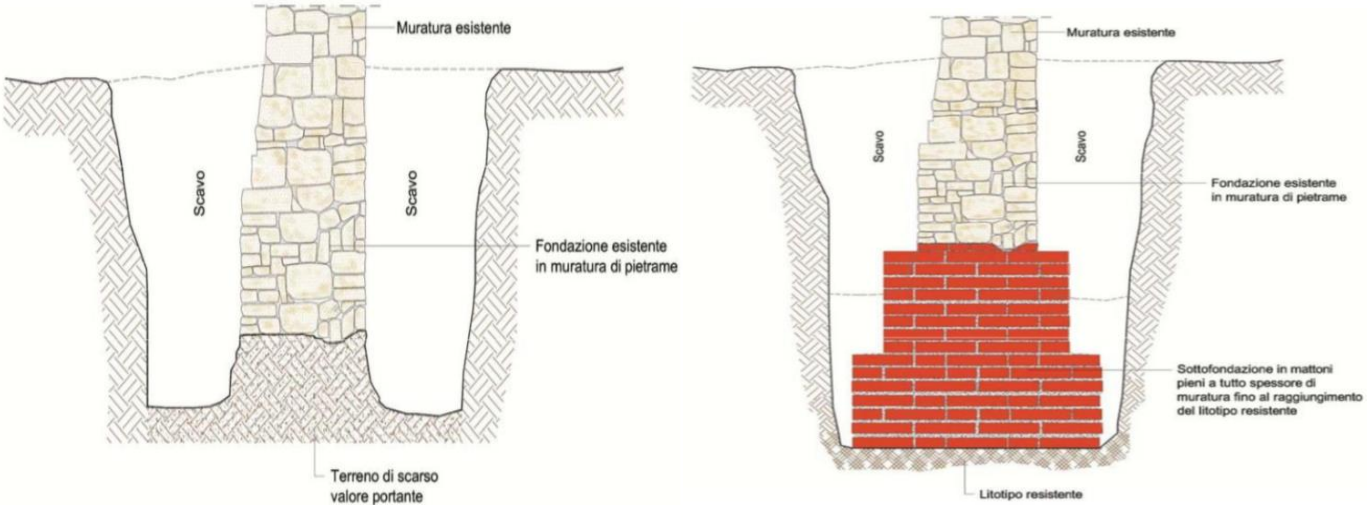

Fig.12-13: Excavation scheme to be carried out alongside the foundation until reaching the bottom level (left image). Solid brick sub foundation system of consolidation (rigth image).

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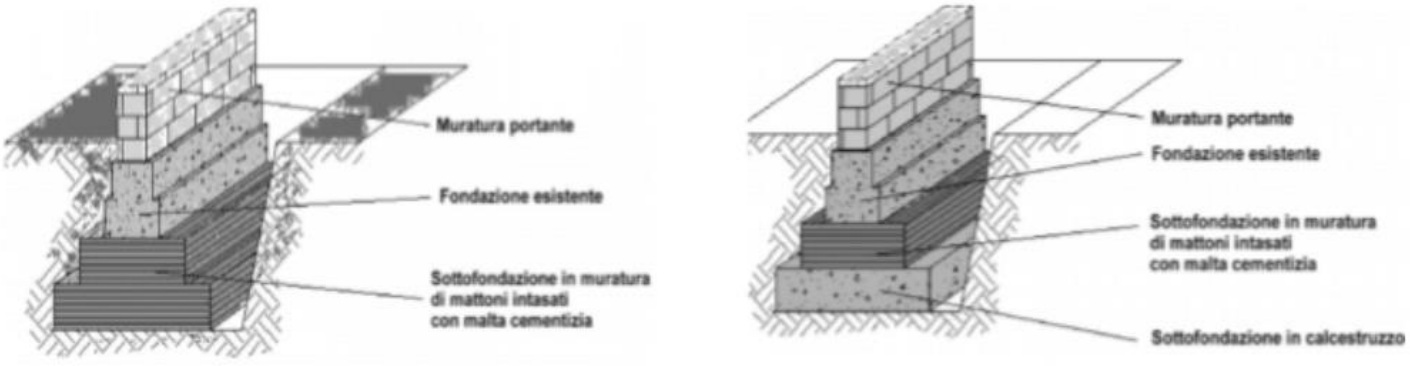

Fig.14: Sub-foundation consolidation. Full brick masonry pattern or solid brick masonry and reinforced concrete layer below. *© Gebbia V., Ristrutturazione e restauro degli edifici-manuale tecnico per il recupero architettonico, Grafill, Palermo, 2013.*

Fig.15: Extension of the foundation base, positioning of the reinforced concrete beam-curb.
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Fig.16: Extension of the foundation base, connection between the foundation and the reinforced concrete beam-curbs.
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Fig.17: Masonry foundation consolidation. © *Mario Li Castri*