Repairs to Teacher Training Academy RC Building in North Cyprus-Case Study

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REPAIRS TO TEACHERS TRAINING ACADEMY RC BUILDING IN NORTH CYPRUS – CASE STUDY

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Abstract

The case study examined is a controversial one, which brought up the discussion of the necessity of subsurface explorations, better site inspection and improved quality of construction technology. The Teachers Training Academy was examined in all aspects, and in contrary to the speculations of poor concrete quality and inadequate reinforcement, numerous cracks formed on the beams and the walls were due to the existing subsurface conditions, the chosen foundation system and inadequacy in the drainage.

Keywords: structural cracks, concrete quality, unconsolidated fill, slope stability, differential settlement

1. Introduction

There has been a growing awareness of construction faults in North Cyprus in the past few years, mainly due to emerging research activities of Civil Engineering Departments of the universities on the island established during the last two decades. Cracks in buildings are no longer accepted as normal; reasons and remedies are sought by the owners. Information on some old cases as well as new case studies are collected by academics doing research in civil engineering practices of Cyprus, to form a data base and to establish diagnoses of specific causes of cracking of buildings in different parts of the island.

The construction faults detected recently mainly arise from soil problems. Recent studies on the soils of Cyprus reveal the fact that they are mostly problematic soils [1, 2]. The climate of North Cyprus is semi-arid with pronounced wet and dry seasons. There has been an appreciable increase in precipitation in the past winter months which has caused certain construction problems to become more evident. Some new development areas were chosen as the old river or lake- beds, which have dried up for many years. The collapse occurring upon saturation of unconsolidated alluvial silts and clays of these beds, and of filled in land not properly compacted, have caused undesirable cracks of the beams, floor slabs and walls of various buildings, even during the stage of construction. The main construction fault is evidently from not having adequate knowledge of sub-soils and therefore not choosing and constructing the proper foundation type. Many light structures in soils of high swell potential are built on single footings in the active zone and therefore are prone to differential movement with changing climatic conditions. The recent heavy rains have proved the inefficiency of the drainage systems, if any, provided around the buildings. The growing interest of planting lawn also increased the susceptibility of swell due to watering, and trees planted close to buildings exacerbated the seasonal volume change. In addition to expansive soil problems, constructing on unconsolidated Holocene formations, which are recent deposits, caused differential collapse of heavier structures upon wetting, hence distortion of the structure. Another common construction fault in civil engineering practices on the island is not to comply with standard compaction control method for manmade ground.

The case study presented in this paper is the Teachers Training Academy building in North Cyprus, which has been constructed recently. As the building was opened for teaching the first time, several visible cracks have been observed vertically in beams and diagonally in partitioning walls at the eastern wing, which increased in number in a couple of months. The Ministry of Education had to evacuate the building due to a growing controversial argument started by the Chamber of Civil Engineers, as to the poor workmanship of concrete and steel works [3, 4].

The importance of the building and the location being a seismic hazard zone increased the “fear of failure”. Therefore, authors were appointed to inspect, appraise and suggest suitable repairs for the building and foundations. Although, upon first inspection, it was evident that the problem was due to foundation movements, to clarify controversial issue, all the possible reasons for the formation of cracks were sought. Inspections, testing and analyses on the quality of the concrete, adequacy of super-structural elements and the existing reinforcement, topography, subsurface soil conditions and the existing foundations were all studied.

This paper presents the observations, analyses and the suggested solutions for the problem using the local materials and the available technology.

2. Observations and Findings

Figure 1 shows the plan of the Teachers Training Academy built in a suburb of Nicosia situated near a river- bank. The building is comprised of 5 blocks over an area of 3000 m^2 connected by expansion joints. Most of the structural problem occurred in block A, which is on the southeast flank of the building.

In order to identify the problem, the following inspections, testing and analyses were carried out.

2.1 Cracks and Concrete Quality

In order to measure the depth of cracks on beams of the suspect part of the building Ultrasonic Pulse Velocity Test was applied according to BS 4408:Part 5:1974 [5]. Readings were taken from 10 main points. The width of the cracks was measured by a microscope. The results of these readings are as given in Table 1. Readings indicate that the beams B224, B230 and B273 (Figure 2) have quite deep cracks, which are greater than the reinforcement cover (25 mm).

In order to check the compressive strength of the suspect part of the structure, three test cores were taken and tested according to BS1881: Part 120:1983 [6]. The concrete grade required by the project was BS20 (20 MPa characteristic cylinder compressive strength at 28 days). The test results given in Table 2 shows that the structure satisfies the requirement of TS 500 [7] for BS20 (Table 3).

2.2 Structural Analysis

Structural analysis carried out and the design of beams and columns of the structure checked according to Turkish Building Code of Requirements [7]. There were no computational and/or design faults.

2.3 Steel Reinforcement

Steel reinforcement of arbitrary beams was checked. Some detailing faults concerning reinforcements at the bottom of some beams, near column supports, were observed. However, this could not be the reason for beam cracks, since such detailing faults were observed in some other beams with no significant cracks.

2.4 Soil Investigations

The building is situated on a recent deposit on a sloping terrain, descending toward a river- bank in the east, with an infinite slope of 20° from horizontal. A test pit excavated to ascertain the soil stratification at the corner of Block A (Figure 1) revealed that the problem area sat on an unconsolidated fill of silty clay, used to level the site, below which is a firmer stratum of the same soil type. The block A is carried by single footings except the columns on axes GK and GM (Figure 2), connected by eccentrically loaded combined footings. The footing depth, observed during excavation of a test pit near the outermost axis (G11) of Block A (Figure 2), is as shallow as 0.40 m. The soil samples recovered from the fill material at the footing depth and from the natural soil, 2 m below the footing depth, were tested in the laboratory to obtain the physical properties, compressibility and undrained shear strength characteristics. Both materials are of the same soil classification, yet the top 1 m is much more compressible than the natural soil below, which is also very compressible, and the undrained shear strength of the compacted fill is much less than that of the natural soil.

3. Discussions

In civil engineering practice, assigning definite physical sizes to structural elements requires consideration of all possible loads that a structure may be subject to during its service life. It is a paramount importance for engineers to predict such possible loads and consider all the possible combinations during the design process. However, in accordance with the design, the engineering supervision on site is essential and the necessary refinements should be considered during applications. Consistency of the application and design should be verified at all stages. In the absence of these basic requirements, several undesired problems might be observed concerning structural elements, therefore, the structure as a whole. However, based on observational and experimental findings of this case study, the problem of cracks, is neither from the load estimates nor from superstructure elements.

The very first observation at the site, as far as soils are concerned, was the possibility of a slope stability problem. Studying the terrain and the subsurface soil properties, evidently there existed a tendency for creep of the topsoil in translational slip, down the slope towards the river-bank, under the effect of the load applied by the building, and the changes in the effective stresses due to heavy rains occurring before the completion of the landscaping. The landscaping should have included terraces of flowerbeds descending downhill, which could prevent lateral movement. In addition to the creep of the topsoil, the walls of the septic tanks built very close to the building were not supported by reinforced concrete walls, as stated in the construction specifications, hence further easing the lateral movement of the soil stratum beneath some foundations.

The construction of the apron around the building, and the placement of the downspouts were done long after the completion of the main parts of the building, hence providing easy access for water to reach the soil around foundation. The fill under Block A was not properly compacted and collapsed upon wetting during the wet season. The single footings along the outermost edge of the eastern part of the building are very close to each other, causing overlapping stresses in the underlying compressible soils, and therefore differential settlements. The collapse of the fill, which is thicker at the corner of Block A, together with the differential settlements of the interior footings along axis G11, caused additional tensile stresses in the beams, which in turn caused cracks in the concrete. These cracks occurred near column supports (Figure 2, Figure 3).

It was observed that, the location of such systematic vertical cracks coincides with the location of the bend-up bars in the beams as indicated in Figure 4. Therefore, these cracks could not have been due to lack of shearing capacity. At these sections, steel area at the bottom is reduced due to the use of bent-up bars. Such applications are common in North Cyprus, as in most of the cases only vertical loads are considered in the structural analysis. However, when a structure is affected by support settlements or lateral forces, cracks might be observed at such weak sections. In other words, beams may not sustain tensile stresses caused by additional forces coming from support settlements. In general, cracks in beams of the suspect building are as shown in Figure 4. These cracks will not have a significant effect on the beam capacity under service loads. However, it should be noted that, during an earthquake, plastic hinges would be formed at the beam-ends, which might cause redistribution of moments through beams and columns. Such phenomenon would not cause structural instability, since the two-storey building considered here has highly rigid columns capable of resisting lateral forces.

The columns on the eastern edge of the Block A are supported by eccentrically loaded combined footings, which are situated in the thickest part of the fill. Both the collapse and the consolidation settlement of the fill might have also caused buckling of the eccentric footings, imposing additional strain to the elements of superstructure.

3. Recommended Solution

It is clear that footings on the eastern wing are on the loose fill material, which cause differential settlements both due to its collapse upon wetting and continuing consolidation settlement of both the fill and the natural soil beneath. The following remedial measures can be taken:

i) Improving the drainage system around the building to prevent wetting of the soil around foundation: A French drain should be constructed during the dry season around Block A, with perforated pipes installed wrapped in geotextile to prevent clogging of the holes. The drainage trench should not be closer than 1 m to the side of the foundations and it should be placed at a depth lower than the bottom of the foundation. It should be backfilled with granular soil. Reinforced concrete apron should be constructed all around the blocks at a minimum width of 1 m. The downspouts should be directed to the drainage system, which will collect the surface water and direct it to the river.

ii) Reconstructing the walls of the septic tanks as reinforced concrete to restrain the soil beneath foundations and stop its lateral movement.

iii) Connecting footings to each other at the eastern part of the building by rigid tie-beams: The edge footings along the axes G11, GK and GM, should be strapped to the interior footings to increase the rigidity of the structure and to avoid eccentricity in the foundations of the latter two axes.

iv) Surrounding the eastern part of the building by a retaining wall system to prevent sliding of Block A. The retaining wall can be a cantilever type, and should be placed deep enough to prevent the movement of the building towards the river- bank (Figure 5).

v) Monitoring cracks [8] on the beams and walls after the completion of the remedial work as mentioned above.

4. Conclusions

Time, effort and money have been spent over the years for repair and maintenance of visible cracks that occur in most of the buildings in North Cyprus. It is a general belief that such undesired results could be prevented by proper design and site inspection during construction. In this paper, a case study regarding the problems of Teachers Training Academy in North Cyprus is presented. It was observed that inadequate drainage and inappropriate foundation system were the causes of the cracks on the beams and the walls of the building. Evaluation of the experimental findings and observations at the site indicated that, lack of soil investigation before the design of project, followed by poor engineering supervision on site yielded these problems. As a result, some remedial measures are suggested for the building. It should be emphasized that, lack of site investigation before design could bring many problems that may cause loss of national resources.

The use of bent-up bars in beams is another factor in beam cracks. In most countries, the use of bent-up bars has been abolished. As Cyprus is in an earthquake region, civil engineering practices should be re-evaluated in the light of code of practice in seismic regions, to prevent possible future disasters.

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Table 1. The depth and width of cracks measured in Teachers Training Academy.

Crack No.	Designation/ Location	Size of Beam (mm)	Width of Crack (mm)	Depth of Crack (mm)
1A	B217/side	250x500	0.70	27
1B	B217/bottom	250x500	NM*	28
2A	B216/side	250x500	0.10	96
2B	B216/bottom	250x500	NM*	28
3	B222/side	400X600	0.04	80
4A	B224/side	250X600	0.36	75
4B	B224/bottom	250X600	NM*	130
5A	B228/side	250X600	0.32	33
5B	B228/bottom	250X600	NM*	12
6A	B230/bottom	250X600	NM*	150
6B	B230/side	250X600	0.08	220
7	B230/G9J**	250X600	0.12	96
8	B234/side	250X600	0.20	75
9	B273/side	250X700	0.22	200
10	B249/side	500X600	0.16	40

*not measured

**Beam – column connection point

Table 2.Test results of concrete cores taken from RC slab of Teachers Training Academy.

Core No.	Designation / location	Core Diameter (mm)	Core Height (mm)	Actual Cube Comp. Str.[1] (MPa)	Actual Cyl. Comp. Str.[2] (MPa)	Potential Cube Comp. Str.[3] (MPa)
1	S212/slab	105	144	30.9	24.72	40.2
2	S216/slab	105	144	41.2	32.96	53.7
3	S217/slab	105	134	26.0	20.8	33.9
Average				32.7	26.20	42.6

[1] Estimated actual cube compressive strength in MPa.

[2] Estimated actual cylinder (150x300 mm) compressive strength in MPa.

[3] Estimated potential 28 days cube compressive strength in MPa.

Table 3. Concrete grades according to TS 500[7].

Concrete Grade	28 days Cylinder (d:150 mm, h:300 mm) Compressive Strength (MPa)			
	Char. Comp. Str. (MPa) F_{ck}	Av. Comp. Str. (MPa) F_{cm}	Min. Comp. Str. at Site (MPa) F_{cm}	Av. Min. Comp. Str. at Site (MPa) F_{cm}
BS 14	14	18	17	17
BS 16	16	20	13	19
BS 20	20	26	17	23
BS 25	25	31	22	28
BS 30	30	36	27	33
BS 35	35	43	32	38
BS 40	40	45	35	43

$F_{cm} \geq F_{ck} + 3$ (MPa)

$F_{cm} \geq F_{ck} - 3$ (MPa)

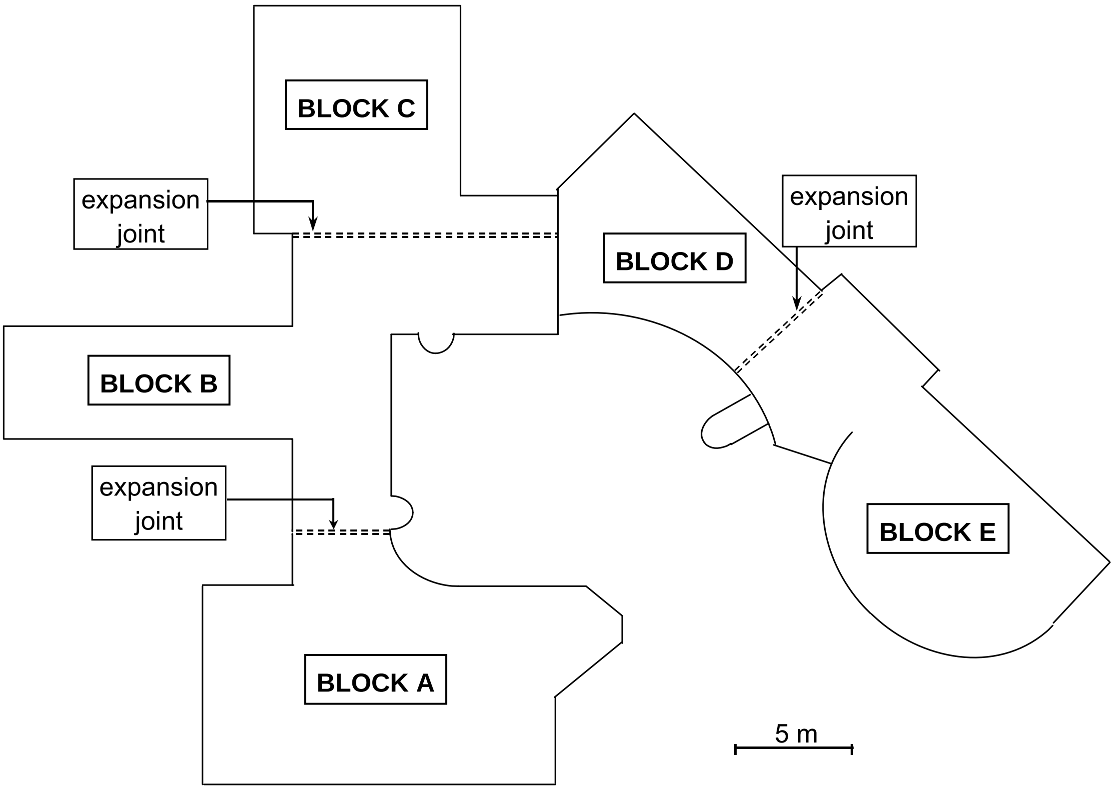

Figure 1. Plan of the Teachers Training Academy.

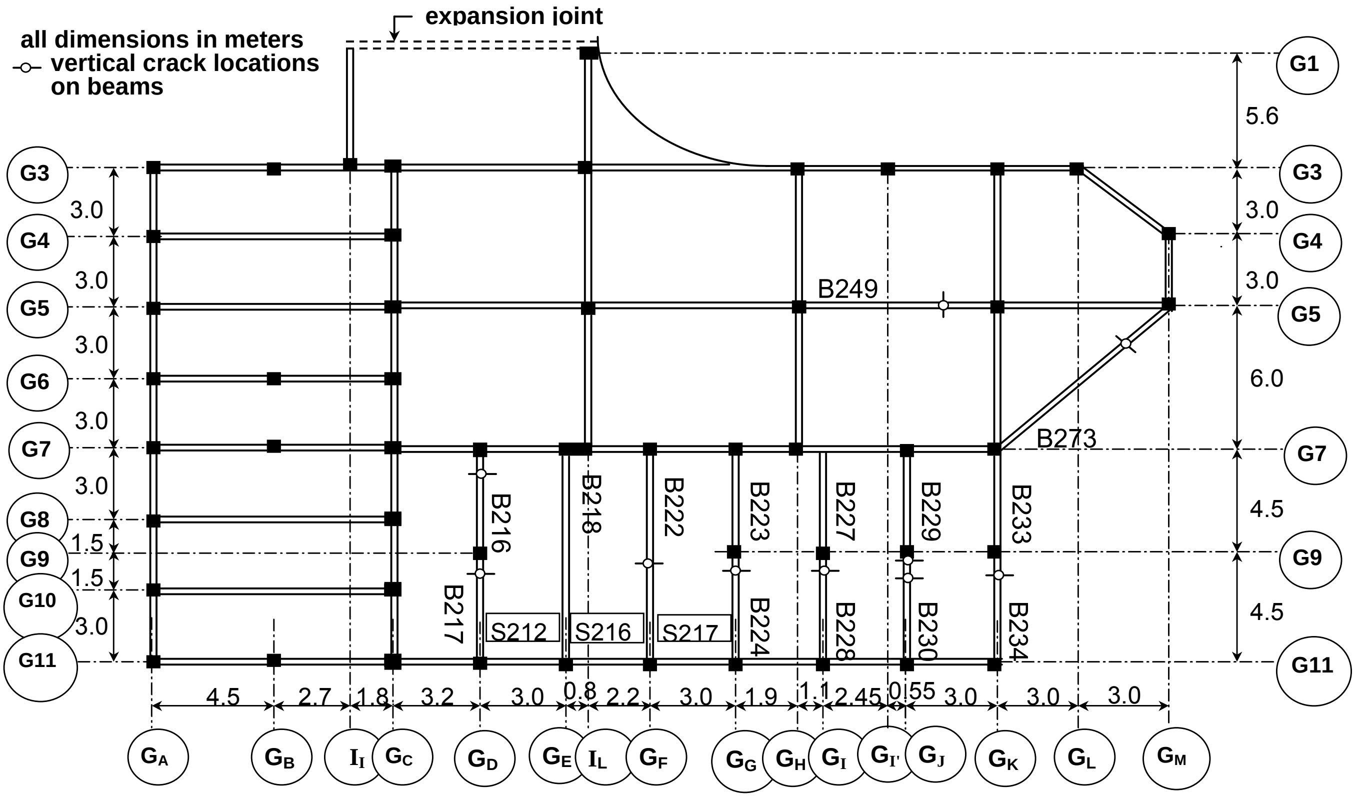

Figure 2. Sketch plan of Teachers Training Academy Block A.

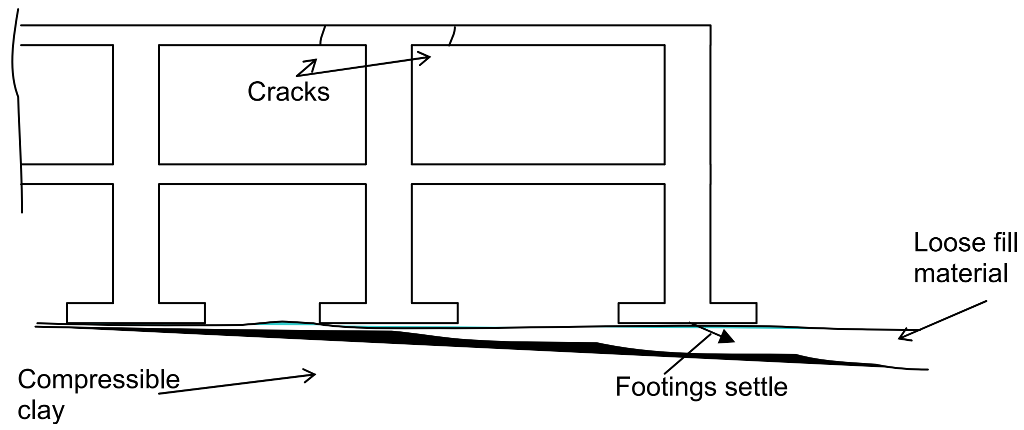

Figure 3. Typical frame: uneven thickness of the fill over the sloping ground.

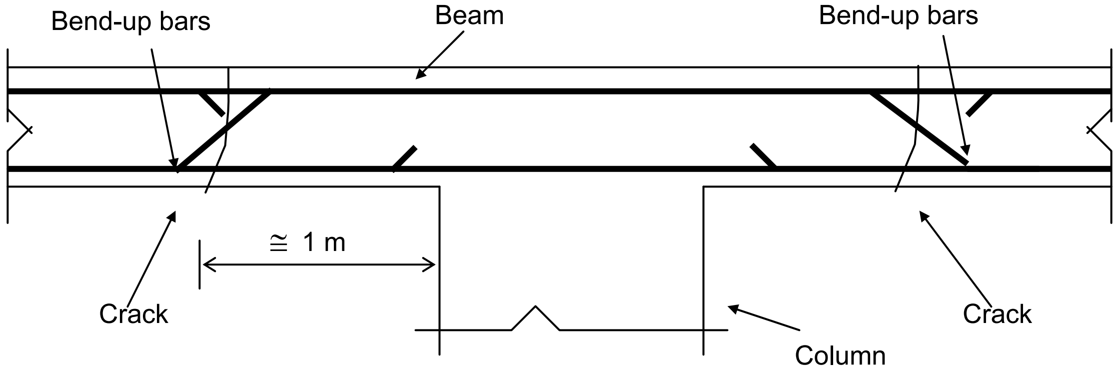

Figure 4. A typical beam detail and location of cracks formed in the beam.

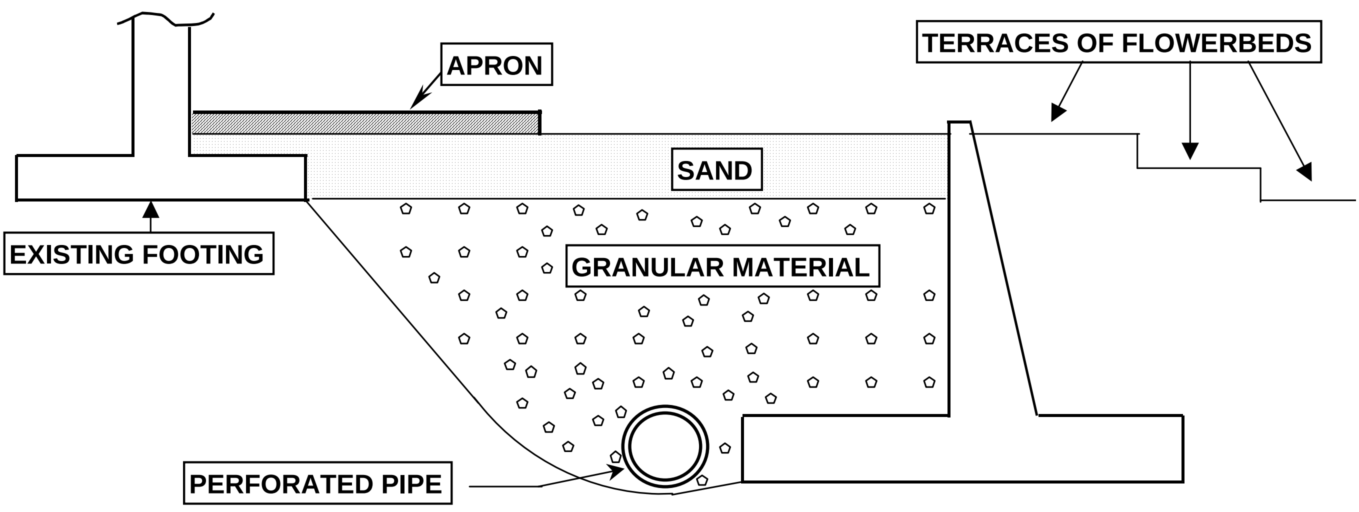

Figure 5. Cross-section of the recommended retaining wall and the drainage system.