CROSS Safety Report

Poor retaining wall design threatens stability of a multistorey steel-framed building

This month's report concerns a poorly designed retaining wall, immediately adjacent to a steel-framed multistorey building, which deflected and imposed significant lateral geotechnical loads into the building's superstructure.

Report

The reporter was called to a building opened some years earlier owing to repeated problems with a screeded floor finish 'popping up' in a corridor. The building is on a sloping site.

To make best use of the site, the building is on two foundation levels, with a 4m retaining wall under the building (**Figure 1**). On the uphill side of the retaining wall, at the back of the building, the construction is single storey. On the downhill side of the retaining wall, the building is a three-storey steel frame fronting a level area after which a series of retaining walls follow the slope down. The steel frame is founded at what is effectively ground level and was designed with minimal weight, suitable for a free-standing structure. It is stabilised by steel flat bar cross-bracing.

There is only one bay of this bracing, so each cross-brace is a critical element. The corridor with the problematic screed is at ground floor level in relation to the back of the building but is in fact a suspended slab as it is at first floor level in relation to the steel frame and a services corridor in front of the retaining wall runs beneath it. The services corridor is at the ground floor level of the front part of the building.

The hillside on which the building stands is extensive, running back up behind the building for a considerable distance. Ground water percolates through the soil.

The issue the reporter uncovered was that the retaining wall was over stressed and, in fact, failing. It had been assumed in the design that the soil behind the wall was granular and fully drained, which proved not to be the case. Added to this, the retaining wall had been conceived as a rigid cantilever wall: no deflection zone had been allowed. The wall was deflecting forward, and the troublesome corridor slab was being squeezed between the moving wall on one side and the steel frame on the other. This was causing the screed to 'pop up'.

What was rather more worrying to the reporter was that the horizontal loads being imparted onto the steel frame were an order of magnitude or more above what this structure's bracing was capable of restraining. Its bracing was designed to stabilise the superstructure, not restrain a hillside of water bearing silty clay. As there was only one bay of bracing a single element failure would have destabilised the entire structure. The corridor screed issue was merely an early warning of a potentially much worse situation in which the cross bracing would snap, and the steel frame then collapse. During the investigation, a history of slab settlement behind the wall was also revealed – another early warning, but one that had been missed.

According to the reporter, the issue was remedied by:

- improving the drainage behind the wall
- building a waling truss in the services corridor to provide additional restraint to the wall. The truss spanned to new anchorage points
- creating a movement zone between the wall and the structure.

Structural movement monitoring was also utilised.

The reporter believes that the origin

Key learning outcomes

For structural and civil engineers:

- Retaining wall designs that rely on dewatering to prevent the build-up of water pressure must be carefully detailed to ensure effective drainage, adequate discharge capacity and long-term maintainability
- Designers should ensure that retaining walls are detailed to prevent unintended load transfer to other structural elements. If loads are transferred, the receiving structure should be capable of safely supporting them
- Retaining wall computer design software may not provide estimates of wall deflections
- The performance of a typical cantilever retaining wall depends on its ability to deflect and mobilise active earth pressure. If the wall's movement is restricted, it may experience higher at-rest earth pressure

of the problem lay in the presumption of fully drained frictional fill behind the retaining wall. This was erroneous as:

- the drainage relied on a flexible 100mm plastic pipe which was not laid to falls and could not be rodded and had silted up
- on a hillside with water percolating through it, back of wall drainage is not just to relieve pore pressure, it is also to divert an ever-continuous flow (in these circumstances it is not reasonable to assume a phreatic surface lowered by drainage throughout the design life of the structure)
- fines carried by the groundwater flow had not only blocked the drainage pipe, but also by the time our reporter came to investigate, had infiltrated the granular fill, rendering it a weak fluid material.

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SCAN ME

The reporter seeks to alert designers and building owners about the potential consequences of lateral geotechnical loads coming to bear on superstructures on stepped sites. On a level site, the soil pressures will at least balance. On a sloping site, the loads are eccentric and will push the building. Movement will be resisted by the bracing, which will most likely prove inadequate and snap or deform, thereby destabilising the entire superstructure. The reporter has seen instances of buildings on stepped sites, with retaining walls under and integral with the structure (as shown in **Figure 1**) in residential, educational and leisure buildings, but comments that examples may exist across all sectors. Where there is a retaining wall under a structure, the designer should confirm that their superstructure is either structurally isolated from or is capable to withstand such geotechnical loads as may develop.

In conclusion, the reporter is of the opinion that for retaining walls within the footprint of a building, as described in this case, the retaining wall is a critical element which needs to be designed to resist the full hydrostatic head and with conservative parameters, and given sufficient space to deform as loads are taken up, and with a movement joint.

Thought should be given to how an idealised design model (fully drained granular fill in this case) might change with time, in this case through loss of drainage and weakening by fines infiltration. A bespoke design fully informed by geotechnical expertise is needed.

The full CROSS Safety Report, including links to guidance mentioned, is available on the CROSS website (report ID: 1420) at **www.cross-safety.org/uk/safety-information/cross-safety-report/poor-retaining-wall-design-threatens-stability-1420**.

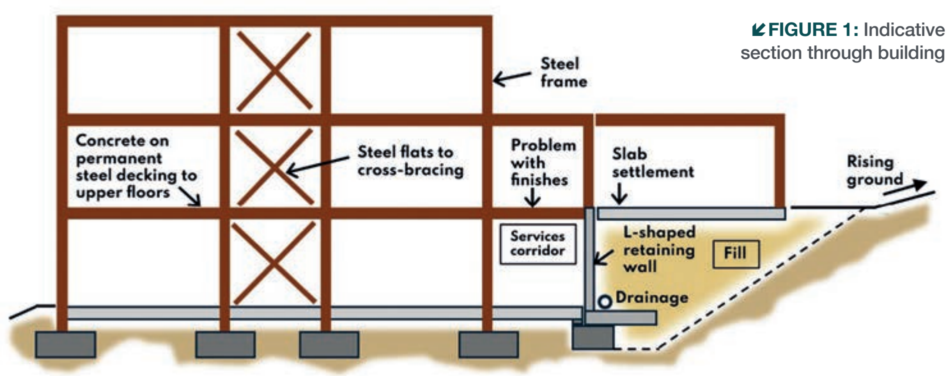

FIGURE 1: Indicative section through building

Expert Panel comments

This is a clear and informative report that highlights the importance of designing and detailing retaining structures to manage associated risks effectively. It reinforces the need to ensure that these structures do not transfer loads to elements that are not intended or designed to resist them.

Where loads are transferred, the affected structures must be capable of safely supporting them, with consideration given to the building's design life and all relevant superimposed loads.

Less robust designs that rely on dewatering to prevent the build-up of water pressure must be carefully detailed to ensure effective drainage, adequate discharge capacity and long-term maintainability. Maintenance requirements should be included in the operation and maintenance manuals within the health and safety file.

Some of the issues described by the reporter arise from a fundamental misunderstanding of soil mechanics. The pressures acting on the rear face of a retaining wall depend on the wall's ability to deflect and mobilise active earth pressure. If movement is restricted, the wall instead experiences at-rest earth pressure, which is significantly higher than the active pressure.

A reinforced concrete cantilever retaining wall might typically be expected to deflect by approximately height/250. In the case described by the reporter, no provision was made to accommodate this movement. Although the forces imposed on the building can be large, they are strain controlled, meaning the structure is forced to displace, but only by a finite amount. In this instance, the resulting enforced displacement led to buckling of the screed.

It is unclear how many retaining wall design packages include an estimate of wall deflection under lateral loading. Without explicit mention in the design output, deflection may be overlooked, especially by those unfamiliar with typical limits. Likewise, many designers may not realise that a retaining wall must move in order to mobilise active earth pressure.

Designers must move beyond the notion that design is simply about calculating stresses and selecting structural members. All structures experience complex movements, and their form and detailing must account for these effects. A deep understanding of the causes and extent of movement, across all materials and structural systems, is essential to good design.

The retaining wall discussed by the reporter seems to have been treated as a relatively minor part of the overall scheme. It is not clear whether the design team fully appreciated the challenges related to its design and long-term performance, or the potential impact if it were to fail. It is also uncertain whether the team had the right expertise in place to define what would count as a failure and how the related risks should be addressed.