

## **The use of micropiles as part of a challenging development on a steep hill-side site in Salcombe, Devon, UK**

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### 1.0 Introduction

Salcombe is a coastal town in the southwest of England. It is situated on the mouth of a fjord-like estuary and is built mostly on the steeply sloping western side of the estuary in a region known as the South Devon Area of Outstanding Natural Beauty (AONB). The town has an extensive waterfront and a naturally sheltered harbour. It has become a very desirable location and many residential properties sell for in excess of £1 million. These high property values and the increasing desirability of the area lend themselves to extensive revamping, remodelling and extending, or even wholly rebuilding, in prime locations with spectacular sea views coupled with the generally pleasant climate.

We have been involved for over two years with one such remodelling/rebuilding project, on a hill-slope property overlooking the harbour. This project has involved the use of drilled and grouted micropiles (including both compression and tension piles), contiguous micropiled embedded retaining walls and permanent and temporary ground anchors and anchor ties. The site access and working conditions were extremely restricted, and required several different types of rig: ranging from conventional 7-12 tonne tracked micropile/ground anchor drill rigs to a dismantle-able walk-in rig, capable of working off scaffold platforms.

The property was located on a steep south-facing slope, facing the sea and the estuary. It fell some 20 metres in vertical level over its width of approximately 30-40 metre: with an average slope of around 30° to the horizontal. A series of masonry gravity retaining walls and structures had been constructed across the slope in past times, giving a terraced configuration. The furthest downslope of these formed the southern, seaward, boundary of the site. The uphill northern boundary was formed by a local access road. The original (now demolished) dwelling was located towards the uphill end of the site.

The site was to be completely re-developed, with new cross-slope retaining structures giving access for the construction of a swimming pool and gymnasium/boiler house. In addition the original house was to be demolished and replaced by a new structure on a similar footprint, and new access-ways were to be formed to the new dwelling. These access arrangements included a turn-table system, to allow vehicles to drive in to the house, and be turned around to drive back out to the main road.

The work involved the design and construction of some 40 permanent and temporary ground anchors and anchor ties across the site, together with almost 70 tension and compression micropiles and 60 contiguous drilled micropiles forming a permanent retaining wall.

An indicative plan of the site is attached as Figure 1.

### 2.0 Ground Conditions

The surface materials over the site comprised a colluvium-type deposit of clayey angular gravel of mudstone/schist to a depth of around 1-2 metres, overlying weathered bedrock, which became stronger and more indurated with depth: typically at around 3-4 metres below ground level. Associated with the existing on-site retaining structures, made ground up to 2-3m depth was also found on the site. Bedrock at the site comprised mica schists forming part of a geological group known as the Start Complex, most probably of Lower Devonian AGE, some 400 million years old. They were formed from previous slates,

siltstones and mudstones, and were metamorphosed into schists during the Hercynian-Armorican (Variscan) earth movements at the end of the Carboniferous Period, some 300 million years ago.

The site is located on the southern limb of a major antiform running generally east-west across the peninsula. Cleavage or foliation dips are generally steep ( $>45^\circ - 70^\circ$ ) and variable in direction, but with a strike generally parallel to the axis of the antiform.

Experience in the area indicates that SPT N-values in these Devonian slaty rocks tend to rise rapidly once test values in excess of  $N=100$  are measured. We generally look for  $N>200$  as being “competent” or “sound” bedrock.



**Figure 1: Location of the Project**

### 3.0 Brief Review of the Works

The works undertaken at the site as part of the development consisted of:

- The construction of a reinforced concrete anchored retaining wall, supported by twenty conventional double-corrosion protected ground anchors, each with a 290kN (65kip) design working load.

- The installation of 175kN (40kip) compression micropiles to support the foundation loads for the new dwelling, which was to be constructed on the approximate footprint of the original (now demolished) building. These piles were installed using the Odex 160 drilling system with a medium-sized tracked Beretta 5-6 tonne rig. With this system the rig installed a permanent 200mm welded steel casing through the overburden materials down to sound bedrock using a rotary percussive down-the-hole hammer and an eccentric lead bit. The borehole was drilled open hole at 160mm diameter thereafter to form the load-bearing rock socket. For these piles the minimum rock socket was required to be 2.0m, and the permanent casings extended a maximum of 7.0m below the working platform.
- The installation of temporary 30° hollow-core ('self-drilling') tension anchor ties to support the buttresses of an existing masonry retaining wall within the site, which had become unstable due to the construction operations.

These had design loads of 120kN/anchor and were installed to minimum depths of between 8.5-10.0m, with load transfer lengths of 3.0m in sound rock using 32mm hollow core bars with 75mm rock bits. They were installed with a scaffold-mounted air-operated rotary percussive drifter hammer with a drill mast bolted to the scaffold.

- The construction of some eighteen compression (200kN/45kip) and tension (50kN/11kip) micropiles to resist the potential braking loads from vehicles using the access roadway to the house from the upper highway, and the loads exerted by a turntable system, which would allow vehicles to be turned through 180° to provide a drive-in/drive-out facility. The micropiles were installed both vertically and at 70° to the vertical. These were again installed using the Odex160 system, and were typically between 7 and 11m in overall length, depending upon their location within the structure on the hill-side site.
- The construction of a 30m long anchored contiguous bored pile wall across the width of the site, to provide separated levels for a swimming pool/fitness complex and sun terrace at the lower level and to support the access road to the house at the higher level. The wall required some sixty Odex240 micropiles, formed with 273mm (11 inch) diameter permanent steel casings with overall lengths varying between 7 and 13 metres. These were all provided with full-length cage reinforcement with configurations depending upon the detailed retained heights and wall loadings. These were installed with a 12 tonne tracked Atlas Copco or Casagrande drill rig. At its western end the new wall crossed over the existing masonry retaining wall, so that in plan the new wall was essentially suspended in mid-air! To provide rig access at this end the site had to be overfilled to provide support to the drill rig, and the drill crew worked from a scaffold platform constructed on the battered slope.

The retaining wall was supported by tension piles (rather than ground anchors) installed at 45° below the horizontal, using Odex140 micropiles (170mm permanent casings and 140mm rock socket). These were typically between 7 and 10m in overall length depending on loadings and the depth to the bearing stratum, and were all socketed into sound competent bedrock. Tension loads of between 60 and 230kN (13 and 52kip) were required, utilising high-yield Gewi-type rebars of 32-40mm diameter. The retained heights were up to six metres, but with quite rapid variations along the wall to accommodate the swimming pool, the fitness complex and the higher level sun terrace. Up to three levels of tension piles were required, to accommodate these level changes, and various architectural and structural constraints.

The lateral support design underwent several changes, to accommodate the opposing pulls of architectural requirements, design changes, engineering constraints (both structural and geotechnical), buildability and access.

Where possible, these micropiles were installed with a small one-tonne Holman Unitrack tracked rig working, from a berm in front of the wall, as it was gradually excavated. At the western end, the rig again had to work off a scaffold platform due to the instability of the fill.

A further complication was that a series of deep (200m plus) boreholes for a ground source heat pump system were installed in the access road behind the retaining wall, and the 45° tension piles also had to be clear of these.

As with any anchored retaining wall, the lower levels of tension piles could only be installed, and the waling beams fixed and cured, after the higher tension members had been sequentially installed and cured. Hence these works were not completed until the early part of 2014.

- The installation of further 150kN Odex115 micropiles for a swimming pool in front of the retaining wall. These again required the smallest available one-tonne Unitrack rig.

#### 4.0 Design Aspects of the Micropiles

All the micropiles were constructed using the Odex drilling system: typically from Odex115 to Odex240 depending on the pile type and load. For these particular works, a permanent welded steel casing was installed through the overburden materials down to sound bedrock using a rotary percussive down-the-hole hammer with an eccentric lead bit. The borehole was drilled open hole thereafter to form the load-bearing rock socket of the required length.

The typical configuration of such Odex piles is shown on Figure 2, below.

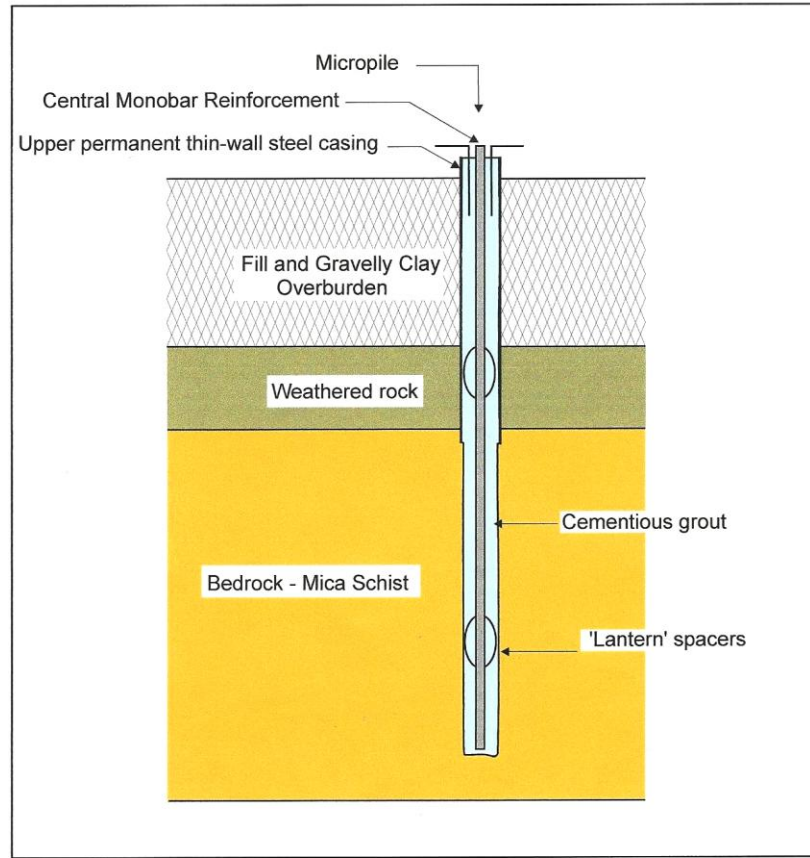
##### (a) Load bearing piles

##### (i) Compression Loads

Any contribution from the overburden or weak/weathered bedrock was ignored for design purposes, and all loads were assumed to be carried by shaft friction in the rock socket. End bearing at the base of the socket was also ignored in design. For design purposes a working skin friction value of 200kN/m<sup>2</sup> was adopted for design. This value was based upon published values for the rock type (e.g. as published in BS8081) but substantiated from a large bank of test data from both micropiles and ground anchors in these geological conditions in South West England. As a rule of thumb we would typically allow a reduction factor of 50% on test values from anchor tests or designs, as compared with micropiles. The main reason for this is that micropiles are typically installed within the relatively near-surface rock strata, whereas anchors are normally installed with a much longer initial penetration into the bearing stratum before forming the fixed anchor length.

The pile loads were relatively moderate, varying from just under 100 to 200kN (225 to 450kips).

All the piles were reinforced with a central deformed fully threaded high yield reinforcing bar installed in coupled lengths. The section design for the piles included the contribution from both the central bar and the surrounding grout, as for conventional pile design. As a normal requirement, however, we would typically require that at least 50% of the design load was carried by the central bar.



**Figure 2: Illustrative cross-section through Odex micropile**

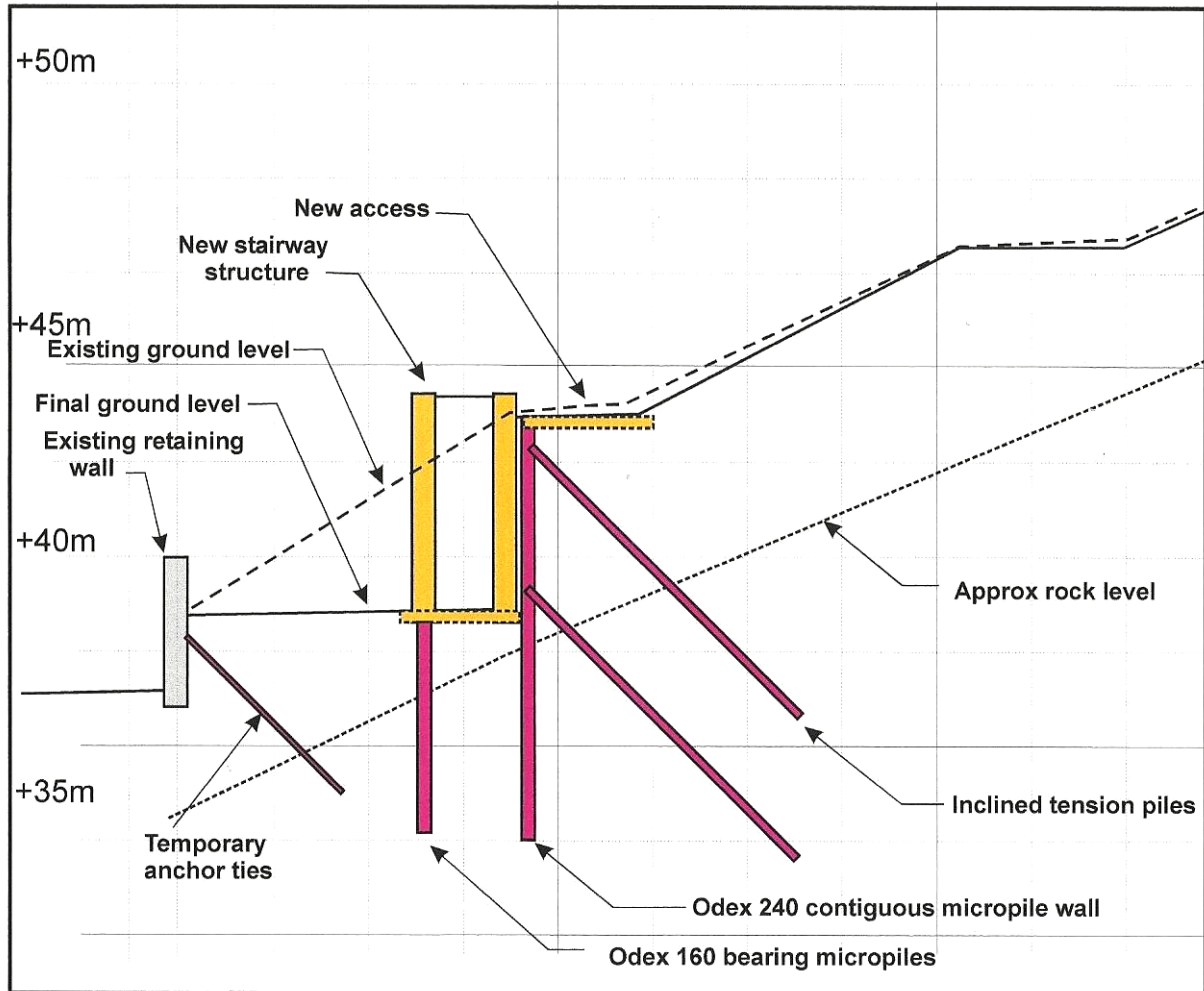
(ii) Tension piles

The tension piles, with maximum loads of up to 230kN, were also designed to transfer their design loads into rock and were also installed more deeply into the schist bedrock to allow a sufficient weight of soil and rock to be mobilised to provide the required pull-out capacity. The design approach was identical in principle to that adopted in ground anchor design.

(b) Retaining wall

The embedded retaining wall was designed as a contiguous drilled micropile wall using Odex 240 piles at 0.5m centres, with a full length 273mmOD permanent casing with an embedment of up to 4m into bedrock. All the wall piles were reinforced with full-length cage reinforcement comprising up to 8 No 32mm diameter high yield bars. The overall retained height of the wall varied between 2m and 6m and the maximum pile length was up to 13m. The wall was restrained by up to two levels (in one location three levels) of inclined tension piles raked at 45° to the horizontal.

Figure 3 illustrates a typical section through the retaining wall.



**Figure 3: Typical section through the contiguous micropile wall.**

### 5.0 Pile Construction

As noted above, a permanent thin steel casing is driven through overburden and weak weathered rock into sound self-supporting rock, as illustrated on Figure 2 above. Thereafter the pile bore is drilled open-hole to its design depth. Upon reaching the required depth the hole is flushed clean and the drill-tools recovered. The central reinforcing mono-bar, complete with centralisers and removable grout tremie pipe is installed to depth, and the hole filled with a neat cement grout. Depending upon pile loads and load transfer considerations, typically either one or two 12 – 16mm short bend-out bars are attached to the top of the central bar for load-transfer into the pile cap or ground beam. If tension loads are to be resisted a suitable steel plate and load nut/lock nut assembly is used.

The pile size installed at Salcombe are summarised in Table 1, below.

An over-riding consideration for the site was the buildability of the proposed works, with limited access to the site, cramped working areas, a steep hill-side location and the possibility of ground instability being caused at critical stages of the work. From the geotechnical works point of view this meant that up to four different drill rigs had to be used on the site ranging from a conventional 12-tonne tracked drill rig to one

that could be broken down into its component pieces, carried in by hand and re-set up in the drilling position.

A further complicating factor was also that much of the work was undertaken in some of the worst weather for over fifty years.

## 6.0 Conclusions

The Salcombe project is a classic of illustration of the versatility of micropiles in such challenging conditions. In size and scope it is relatively small but the number of variations on the micropile theme presented by the project run the full range: from compression and tension piles, vertical and raking configurations, contiguous piled retaining walls and restricted access working.

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**Table 1: Summary of pile configurations**

Pile Designation	Casing O.D. (mm)	Borehole Diameter in rock (mm)	Pile Load		Minimum Rock Socket length (m)	Typical overall length (m)
			(KN)	(kip)		
Odex115	140	115	150	335	2.5 – 3.0	5 – 8m
Odex160	200	160	175 to 200	400 to 450	2.0 – 3.0	7 – 11m
Odex160 (Tension) (70°)	200	160	50	110	4.0	8.0m
Odex 140 (Tension) (45°) Retaining walls	170	140	60 to 230	135 to 515	3.0 – 4.0m	7 – 10m
Odex 240 (Retaining Wall)	273	240	N/A	N/A	N/A	7 – 13m