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Foundations in differing environments

Fondations dans des environnements différents

Foundationen bei verschiedenen Umweltsbedingungen

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SUMMARY

The selection of structural form for foundations is greatly influenced by the techniques available for their construction in the particular ground and environmental conditions. The adoption of a particular design may be determined solely by the availability of a specialized construction method, the structural form being unrelated to that of the superstructure.

The paper describes the effects of the environment on the development of construction methods for foundation works and their influence on structural form. Different environmental conditions will be considered.

RESUME

Le choix du type de fondation est fortement influencé par les méthodes de construction utilisables dans un sol et un environnement donnés. Une conception particulière peut être déterminée uniquement en fonction d'une méthode spéciale de construction, la forme de la structure de fondation étant sans relation avec celle de la superstructure. L'article décrit les effets de l'environnement sur des méthodes de construction pour les travaux de fondation et leur influence sur la forme de ces structures. Différents cas sont présentés.

ZUSAMMENFASSUNG

Die Wahl einer Fundationsart wird beeinflusst durch die verfügbaren Bautechniken und die Umweltbedingungen des betreffenden Baugrundes. Die Ausführung eines Projektes hängt allein von der Verfügbarkeit einer spezialisierten Ausführungsmethode ab, wobei die konstruktive Ausbildung von derjenigen des Ueberbaus völlig unabhängig ist. Der Beitrag beschreibt die Einflüsse der Umweltbedingungen auf Fundationsmethoden und deren Einfluss auf die Form von Tragwerken. Verschiedene Umweltbedingungen werden beschrieben.



THE GREEN FIELDS SITE

The location of a project on a green fields site implies construction on dry land in a temperate region with freedom from the difficulties involved in construction close to existing property. In these conditions the selection of structural form for the foundations is governed by the form of the superstructure and by the ground conditions.

In ground with good supporting characteristics the form of the foundations is simply the downward extension of the superstructure. Load-bearing walls are extended in the form of continuous strip foundations and columns are terminated in simple pad foundations. Design tends to follow traditional lines and is little influenced by construction techniques, although the development of efficient mechanical plant for earthmoving and compaction tends to favour shallow foundations at a nominal depth on graded terraced sites rather than tailoring foundation levels to suit the contours of the ground or the profile of a particular bearing stratum.

In some conditions the structural form of the foundations is determined by conditions other than the layout and loading of the superstructure. Where buildings are sited on expansive clays or shales the uplift forces from the swelling ground can greatly exceed the superstructure loading. The development of rotary auger drilling equipment for clays and shales has favoured the provision of deep pile or pier foundations as a means of isolating the building from the swelling forces by constructing it on beams and slabs supported clear of the ground. The alternative method is to provide a substructure founded at a relatively shallow depth with sufficient stiffness to prevent excessive upward curvature from the uplift forces. This method is more labour-intensive and not amenable to mechanization.

Heavy structures sited over weak ground on the green fields site will usually require some form of piled foundations. The driven displacement pile is usually selected in preference to the bored and cast-in-place pile because it mobilizes a higher proportion of the available skin frictional and endbearing resistance of the soil, and also for reasons of economy and rapidity in installation. The latter consideration is influenced by the development of light easily transportable piling rigs with a diesel or drop hammers capable of being operated by a small crew.

For light to moderate loadings the jointed precast concrete pile is likely to be the most economical type although the driven and cast-in-place pile may be cheaper in conditions where lateral ground displacement is not detrimental to the formation of the cast-in-place shafts. For very heavy foundation loadings the development of large diesel and steam-operated piling hammers has enabled large diameter steel tube piles to be installed with carrying capacities matching those of bored piles installed by plate auger or grabbing oscillator rigs.

As an alternative to piled foundations deep compaction techniques can be considered as a means of consolidating and stabilizing weak granular soils and fill materials thus enabling shallow strip or pad foundations to be used. These techniques comprise either the insertion, at a close spacing, of mechanical vibrating units to form columns of compacted soil or stone in the ground, or the compaction of the soil to considerable depths by dropping heavy weights on to the ground surface.

Where basements are required for buildings, the efficiency and high performance



of modern earthmoving equipment will usually lead to the selection of a substructure consisting of free-standing cantilever retaining walls constructed in an open excavation with sloping sides. Even in poor or water-bearing ground it will usually be more economical to slope back the sides of an open excavation to a stable angle rather than to construct the basement in an excavation supported by anchored or strutted sheet piling. Wellpoint or bored-well ground water lowering systems permit the adoption of quite steep slopes to open excavations in water-bearing granular soils.

Bridges in the green fields environment usually take the form of traffic separation structures with relatively short spans. Continuous deck slabs or girders are frequently used for three or four-span highway bridges and these structures are sensitive to small differential settlements between adjacent piers. This often leads to the adoption of piled foundations in soils of relatively high bearing capacity. Construction of shallow spread foundations is usually much cheaper and far more trouble-free than piling operations. Hambly (1) reported that the cost of piled foundations for a bridge may be comparable to that of the deck. Therefore designers should give careful consideration to the reliability of forecasts of differential settlement, and to the effects of rate of settlement of the foundations at the successive stages of construction of the bridge superstructure before deciding that piled foundations are unavoidable.

THE URBAN SITE

The selection of form of the substructure for projects in an urban environment is influenced not only by the layout and function of the superstructure but also by the proximity of existing bridges, highways, railways and underground services. At the construction stage there is the need to avoid or minimize nuisance to the public by noise, construction vibrations, dust and mud.

In good ground conditions the construction of shallow spread foundations should not present any special difficulty or nuisance and, as in the case of the green fields site, the structural form is usually a simple downward extension of that of the superstructure.

In weak ground which necessitates the provision of piled foundations consideration of noise, vibrations and lateral ground displacement usually rule out the selection of driven displacement piles, although small displacement steel piles have been used on sites surrounded by existing buildings, and considerable progress has been made in developing techniques for absorbing the noise of the impact between pile and hammer.

A wide range of construction equipment is available for installing bored and cast-in-place piles for moderate to very heavy loadings. In particular the auger-injected pile in which cement mortar or concrete is pumped down the hollow stem of a continuous spiral auger is a suitable type for installation close to existing buildings. The barrette foundation, constructed by grabbing under a bentonite slurry to form rectangular, tee-shaped or L-shaped excavations filled with concrete placed by tremie pipe beneath the slurry, is also a suitable method of construction for work close to existing structures.

Piling is not the only method which is available for the construction of deep foundations in the urban environment. In Hong Kong extensive use is made of deep shaft foundations constructed by hand digging in a circular excavation



about 1 to 3m in diameter (2). The excavation is taken out in 0.6 to 0.9m deep stages. Concrete cast-in-place behind circular formwork is used to support each stage.

The site of the 50-storey tower of the Development Bank of Singapore was very narrow and was bounded on two sides by heavily trafficked roads and on the other two sides by deep basements beneath the podium structures of the new development. These restricted site conditions together with the presence beneath the site of deep fill and soft alluvium followed by steeply dipping and highly weathered sedimentary rocks led to the selection by the consulting engineers, Steen Sehested and Partners, of hand excavated circular shaft foundations beneath each of the four columns supporting the tower (3). Each column carried a load of 180 MN and the 7.3m diameter shafts were taken down to depths between 40 and 64m to reach moderately weathered rock of the required bearing capacity.

The techniques of constructing retaining walls in the form of a concrete diaphragm cast-in-place or in precast concrete slab form in a trench excavated with support by a bentonite slurry has enabled structures such as deep basements, cut-and-cover underground railways and highway underpasses to be constructed in close proximity to the foundations of existing buildings. These forms of construction are the first choice in weak or water-bearing soils but other methods which are available include ground support by contiguous or secant bored piles, or concrete panels cast-in-place between vertical steel H-section soldiers. Hand excavated caissons were used in conjunction with concrete jack arches and steel Universal beams for the retaining walls of the Diamond Hill Mass Transit railway station in Hong Kong (4). These caissons are constructed by excavation to founding level in stages of 0.6 to 0.9m. The ground at each stage is supported by concrete cast-in-place behind circular formwork.

Retaining walls constructed in a trench or as contiguous bored piles are frequently used in conjunction with permanent support by intermediate floor slabs or by deep horizontal reinforced concrete walling beams in order to provide a clear working space for excavation within the retaining walls of deep basements (Fig 1).

An important adjunct to the design and construction of deep basements in the urban environment has been the development of instrumentation to monitor the vertical and lateral deformation of the ground beneath and in areas surrounding the basement as excavation proceeds (5). Although decisions must be taken on the design and construction method for the basement before the instrumentation is installed, the records obtained of ground movements are an essential check on assumptions made at the design stage, particularly on the effect of the excavation on surrounding buildings. More important, the case records are of value to the future planning and design of similar structures when the engineer can proceed with greater confidence on his ability to predict ground movements surrounding a deep excavation. Such accumulated data from the monitoring of deep excavations in central London enabled engineers to proceed confidently with the construction of an underground car park within an 18.5m deep excavation sited a few metres away from the Big Ben clock tower and the historic Westminster Hall (6).

If possible, piling should be avoided for the foundation of bridges close to existing railways in restricted urban sites. This is because of limitations imposed by the railway authorities on the type of plant which can be operated close to their running lines, and on the possibilities of deformations to rail tracks caused by ground heave when displacement piles are used, or loss of



ground with bored pile installations. Shallow spread foundations should be adopted if at all feasible, in conjunction with simply supported bridge decks where settlements are expected to be of appreciable magnitude.

The techniques of pipe jacking have been developed to enable large units to be jacked horizontally over considerable distances thereby providing a means of constructing bridge pier foundations and abutments beneath existing roads and railways without disrupting traffic flow. These techniques were used for the foundations of Old Ford Bridge in London (Fig 2). Three tiers of precast concrete units were used for the abutments and central pier. Each tier was jacked horizontally from thrust pits constructed at the ends of the three substructures (7).

REDEVELOPED INDUSTRIAL LAND

In Britain extensive redevelopment is being undertaken on land previously occupied by heavy industries such as steelworks, foundries and shipyards. These sites are characterised by deep deposits of loosely-placed miscellaneous fill material often concealing massive brick and concrete foundations, pits, culverts, and worked-out quarries. The fill material may include chemical wastes which are aggressive to buried concrete and steel in new foundations, or which may undergo large unpredictable settlements as a result of solution by seepage water or by biological degradation. Some fills may contain materials liable to spontaneous combustion when exposed or disturbed.

Redevelopment of these sites often takes the form of light industries and warehousing, making it possible to construct the new buildings on shallow pad or strip foundations. Settlements of the foundations can be minimized by subjecting the levelled and graded ground surface to heavy dynamic consolidation by the dropping weight method. This avoids difficulties in installing piles through ground containing massive obstructions, and the need for protection of pile shafts against aggressive conditions in the fill. Fills containing degradable waste material may have to be removed and replaced by inert materials beneath the sites of individual structures.

SWAMPLANDS

Swamplands in tidal estuaries or in the deltas of major rivers are characterised by soils of highly variable characteristics and compressibility. Soil characteristics vary at close intervals as a result of changes in the course of the river or its distributaries within the meander belt or in the zone influenced by encroachment of the sea. Deep channels filled with peat and highly compressible organic clays are flanked by sand bar deposits of moderate to low compressibility. The seaward margin of deltas may be occupied by a belt of sand dunes.

Development of swamplands usually involves reclamation to raise ground levels above river flood or tidal levels and to allow effective drainage of building sites. The imposed loading from a few metres of reclamation fill has the effect of accelerating the natural process of consolidation of the swamp soils and large settlements of the ground surface may continue for a period of years. Henkel (8) described how a total thickness of 7.5m of pumped sand fill was required to raise the ground surface by 2 to 2.5m in the reclamation of swampland in Lagos where former tidal creeks had been infilled with very soft organic clay. Settlements continued for more than five years. On the other



hand settlements of less than 0.2m have recently been recorded as a result of pumping-in about 3m of hydraulic fill to reclaim swamps in another area of Lagos where the subsoil is predominantly sandy.

Detailed subsoil exploration of a deltaic site can delineate zones of compressible clay soils enabling buildings to be sited on the less compressible sandy deposits. Shallow spread or slab raft foundations can be adopted on the reclaimed ground surface. With careful attention to detailing of the foundations and superstructure high quality buildings can be constructed on shallow articulated reinforced concrete slab and beam foundations even in conditions where the reclaimed ground surface is underlain by soft compressible clays. The foundations of an office building on a reclaimed site near San Mateo, California, are shown in Fig 3. At this site 1 to 1.2m of fill were placed over 12 to 13m of soft bay mud (9). Precast concrete panels were used between reinforced concrete columns to stiffen the walls of the structure. Settlements had exceeded 0.3m after a period of 6 years and were still continuing but with no structural damage being reported.

Piled foundations should be avoided if at all possible because of the need to provide for high dragdown forces on the shafts of piles and the likely need to take the piles down to a considerable depth to reach a competent bearing stratum. Where piles are necessary for bridge foundations severe difficulties can be caused by large relative settlements between the bridge structure and embanked approaches.

When hydraulic fill is allowed to drain above ground water level it becomes compact and capable of supporting shallow spread foundations with moderately high bearing pressures. However if the fill is placed through water, as in the seaward extension of a reclamation project, it remains in a very loose compressible condition. Where fills are dumped through water on to very soft seabed mud the resulting massive lateral displacements (mud-wave formation) can continue over a long period of years, causing severe difficulties with piled foundations in the reclaimed areas. The dynamic consolidation process can be used to compact the ground with depth thereby avoiding the need for piling. If required the dropping weight can be operated through water to compact fill placed in layers by bottom-dumping barges for the foundations of heavy structures such as dock installations and breakwaters.

ARID REGIONS

Intensive urban and industrial development of coastal lands in arid regions is being undertaken in several Middle Eastern countries. Soils in these regions frequently consist of alluvial silts sands and gravels, uncemented or weakly cemented by calcium carbonate or chloride salts. The cemented soils are hard in consistency enabling high bearing pressures to be adopted for shallow foundations. Perversely however the principal difficulty in foundation design in these arid regions is caused by water flow when surface erosion and weakening of the cemented soils occurs under sheet floods originating in mountainous regions inland.

It is necessary to take foundations below the zones of potential erosion in the form of deep strip or pads, and bearing pressures should be based on the characteristics of the uncemented soil layers. The design of piled foundations should take into account the possibility of the installation method, whether by driving or boring, causing breakdown of the cemented structures of the soil and weak carbonate rocks, with consequent loss of skin friction and end bearing resistance. Equipment must be capable of either



driving piles to a considerable depth to get below zones of potentially unstable or cavernous soils and rocks, or of drilling deep cased holes in difficult ground for some form of cast-in-place pile.

Collapsing soils may be present in arid or semi-arid regions. These soils, of which loess is a typical example, consist of an open-structured agglomeration of weakly cemented fine particles. When in a dry undisturbed state they have an appreciable strength and low compressibility, but when exposed to flood water or to seepages from leaking drains the cementing medium may be destroyed causing collapse of the soil structure and massive subsidence. Sometimes these soils are treated by prewetting before constructing shallow spread foundations. Abelev (10) described the installation of deep foundations formed from columns of compacted wetted soil placed in holes formed by driving in a mandrel, or by firing a string of explosive charges suspended down a small diameter drilled hole.

ARCTIC AND SUB-ARCTIC REGIONS

A feature of these regions is the depth of soil affected by frost penetration, and the problems caused to the engineer by the effect of freezing and thawing of the soil on the design of foundations. In sub-arctic regions the ground may freeze in winter to depths of a few metres causing substantial heave of the ground surface. The spring thaw causes collapse of the heaved ground. It is the usual practice to take foundations below the zone of seasonal freeze-thaw by means of basements, piers or piles. Where pier foundations are constructed in drilled excavations the uplift ("adfreezing") forces can be minimized by surrounding the piers with a layer of non-frost-susceptible gravel.

Foundation problems are of much greater severity in arctic regions where the ground is permanently frozen. In these regions the "permafrost" is blanketed by a few metres of soil which is subject to seasonal freezing and thawing. The permafrost can extend to very great depths, as much as 1500 metres having been recorded. Permafrost soils are highly compressible and creep substantially under foundation bearing pressures as a result of recrystallization and repacking of ice within the pores of the frozen soil. Permafrost also contains unfrozen water which can migrate from one zone to another as a result of temperature or pressure gradients in the soil mass with consequential large volume changes.

Where structures cannot be founded on stable ground such as rock outcrops, the principle generally followed in foundation design is to avoid, as far as practicable, any change to the regime of the permafrost. This is achieved by elevating the structure above the ground surface so that the soil is exposed to freezing winds, and with the minimum of heat transfer from the building to the ground. The foundations take the form of piles set into holes drilled deeply into the permafrost (11). Driven piles are not used because of the risk of splitting the ground thus forming channels for the flow of unfrozen water. Holes for the piles are drilled by mechanical auger, or in the USSR by reverse circulation drilling with steam jets, or by gas burners to provide the circulating medium in the form of a hot air blast.

EARTHQUAKE REGIONS

Construction processes have an influence on the selection of structural form for foundations in an earthquake region. If, for example, investigations to



determine the liquefaction potential of the soil show that the ground may become unstable under earthquake-induced vibrations, deep compaction techniques using the dropping weight method or the insertion of mechanical vibrating units can be used to consolidate loose granular soils. These techniques can eliminate or greatly minimize the susceptibility of the soil to liquefaction, thus enabling conventional shallow foundations to be used. It is then necessary to ensure that there is full continuity between the foundations and superstructure, and that pad foundations or strip foundations in crosswall structures are tied together by transverse ground beams.

Fine-grained soils such as silts and clays cannot be compacted effectively and where heavy foundations are sited on weak compressible fine-grained soils, then some form of piled foundation is required. Driven piles are likely to be the favoured type because of the capability of cylindrical steel or continuously reinforced precast concrete piles to assume a curved shape caused by variations in lateral ground displacement without failure in bending or shear. As already noted diesel or steam-operated hammers are available for driving large diameter preformed piles. Alternatively steel or precast concrete cylindrical sections can be installed in holes drilled by rotary mechanical augers or grabbing/oscillator rigs. Piling may have to be extended to considerable depths in order to reach a stratum capable of carrying the pile loadings in end-bearing. This is because of possible loss of skin friction on the pile shaft under earthquake-induced vibrations.

RIVER CROSSINGS

Selection of construction methods for the foundations of bridges over waterways is governed by the environmental conditions which in turn influence the design. If the width of the waterway enables the crossing to be made in a single span the piers or abutments can be located on dry ground with the construction site protected as necessary against flooding. Construction on a land-based site permits a wide range of techniques to be adopted. Selection of the appropriate type depends on the depth of excavation to reach foundation level, on the depth of any piled foundations, and on the general form of the substructure.

Where piers are required to be sited within the waterway then the dominating environmental conditions which affect construction methods are the depth of water, the velocity of flow, the depth of bed scour and the need or otherwise to maintain navigation in the river.

A conventional form of construction of river piers provides for steel sheet piling driven around temporary staging to form a cofferdam. Excavation for the pier base is taken after pumping-down the water in the cofferdam, or the excavation and pier base concreting may be performed under water. However in deep fast-flowing water it may be impossible to pitch and drive sheet piling, and in conditions of deep river bed scour cofferdams may be undermined. Although it is feasible to pitch and drive steel sheet piles in long lengths to take them below potential scour zones there is a risk of piles becoming deflected and interlocks becoming separated, particularly when driving the piles through ground containing large gravel, cobbles and boulders. Cofferdams are also liable to damage by collision with ships or barges, and where they form an obstruction to river flow under flood conditions the cofferdams may be carried away by pressure from the build-up of floating debris or ice.

The Japanese steel industry has developed a method of constructing large bases for the piers of river bridges in the form of interlocked large diameter steel tubular piles. The piles are locked together to form a peripheral structure



of circular, rectangular or double D-shapes (Fig 4). This form of construction has a high strength to resist lateral forces from river flow and impact from vessels or floating debris, and the piles can carry high axial loads from the bridge piers. The piles, which may be one metre or more in diameter, are provided with circular interlocks and have been driven to depths of more than 40m below the river bed. In cases where the pier is located below water level the piles can be extended above the base to form a cofferdam in which the pier is constructed.

Caissons are an alternative form of construction for bridge piers in wide fast flowing rivers where the bed is subjected to deep scour.

Open well caissons are a traditional method of constructing bridge foundations on the Indian sub-continent, where the method is still in use to the present day. Electric power transmission towers are being constructed over the Jumana (Brahmaputra) River in Bangladesh. The river is about 11km wide from bank to bank at the site of the power line crossing. The main river channels can move considerable distances with islands disappearing and re-appearing elsewhere in one season. The calculated regime scour depth is 46m with local scour around foundations of up to 70m below high water level. For these conditions the consulting engineers, Rendel Palmer and Tritton, have designed circular caisson foundations, 13m in diameter, to be sunk to depths of up to 105m. Sinking the caissons through the sandy deposits is being facilitated by continuous circulation of a bentonite slurry from cutting edge level up the outer skin of the caisson.

The foundations of the main towers and anchorages of the suspension bridge over the Humber Estuary, the world's longest span, are an example of selection of foundations of differing types as determined by the environmental and geological conditions. The river is wide and shallow and the meandering channels are subjected to deep scour. Chalk outcrops on the north bank of the estuary where it was possible to construct the anchorage and main tower pier on conventional shallow spread foundations. The south main pier was constructed within the river and the consulting engineers, Freeman Fox and Partners, designed twin circular caissons 24m in diameter sunk by open-well grabbing through 40m of estuarine sands and gravels to a penetration of 7m into very stiff Kimmeridge Clay (Fig 5). Bentonite slurry was again circulated around the outer skin of the caisson to facilitate sinking. The south anchorage was constructed on land at a location where 27m of soft alluvial clay and glacial deposits were overlying the Kimmeridge Clay. It was necessary to take the foundation down to a depth of 35m to resist the 38 000 tonne horizontal pull from the bridge cables.

The 72m by 44m anchorage block was constructed in the form of a multi-cell structure constructed by diaphragm wall methods. By excavating the soil from the individual cells within the diaphragm walls swelling and softening of the Kimmeridge Clay beneath and around the anchorage was avoided (12).

MARINE LOCATIONS

The environmental conditions of winds, waves and tidal stream flow are the dominating influences in the design and construction of foundations in marine locations. For works near the shore such as jetties or island terminals for tankers or ore carriers the favoured method of construction is driving large diameter steel tubular piles. These have a high resistance to lateral forces from waves and currents, and their flexibility provides a means of absorbing



energy from the impact of ships on the berthing structure.

Where lateral forces are limited to those from waves and currents, as in approach trestles to berthing structures, or in ore conveyor trestles, precast concrete cylindrical piles are suitable for easy to moderate driving conditions below the sea bed.

In sheltered waters piles can be driven from pontoons, but the use of jacked-up barges enables large diameter piles to be handled and driven with little interruption by sea conditions. Rotary or grab-type drilling equipment can be mounted on the barges for use where conditions below the sea bed require alternate drilling and driving to achieve the required depth of fixity for piles carrying lateral and uplift forces. These conditions were present in the Firth of Forth, where a tanker terminal for the British Petroleum Company was designed by Babbie, Shaw and Morton (13). Steel tube piles of 2.2m diameter were provided for the berthing structures. These were taken down to rockhead through ground containing large gravel, cobbles and boulders, by alternate driving and drilling out the soil from within the pile tube by a rotary full-face drilling bit and reverse circulation to remove the drill cuttings (Fig 6). On reaching rockhead the drill was used to form a socket for a 560mm tubular anchor grouted into the rock to resist a 7.4 MN uplift force.

The most severe environmental forces on marine structures are those prevailing where petroleum production platforms are sited in deep water. These conditions necessitate constructing the platforms in sheltered locations, towing them as a single unit to the deep water site and securing them to the sea bed as quickly as possible before the onset of storms which might undermine or overturn them.

Two basic methods have been evolved for designing the foundations of the deep water structures in the North Sea oilfields. The first is the open steel tubular structure designed either as a self-floating unit (Fig 7) or to be carried by barge to the site where it is sunk and pinned to the sea bed by tubular piles. The piled structure has the advantage of being capable of installation in a wide variety of soil conditions below the sea bed. It can be used where deep soft clays are present, or on a rocky sea bed where the base structure can be pinned to the rock by drilled-in anchors. The principal disadvantage is the need for attendance by heavy crane barges over the period of pile driving with costly delays in bad weather conditions.

The second basic design approach is the reinforced concrete multi-cell caisson in which wind, wave and current forces are resisted by gravity and the frictional resistance of the massive structure bearing on the soil at sea bed level. Undermining by scour is prevented by a steel skirt around the perimeter of the caisson base, and grout is injected to fill voids between the underside of the base and the sea bed. The principal advantage of the gravity caisson structure is that it can be towed to the sinking site complete with the drilling deck and accommodation units, thus involving the minimum period of attendance by floating construction plant at the deep sea location. However, the sea bed soil must be sufficiently stable to prevent excessive settlement or tilting under the high cyclic bearing pressures imposed by storm waves on the caisson structure.

The gravity base platform illustrated in Fig 8 was designed and constructed by Howard-Doris Ltd for the Ninian Field of Chevron Petroleum (UK) Ltd. The structure is 167.4m high from base level to the top of the deck. The base has a diameter of 140m and the water depth is about 135m at the North Sea location.

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Fig 1 Ground anchor installation and excavation beneath the ground floor slab of a basement substructure, Victoria Street, London

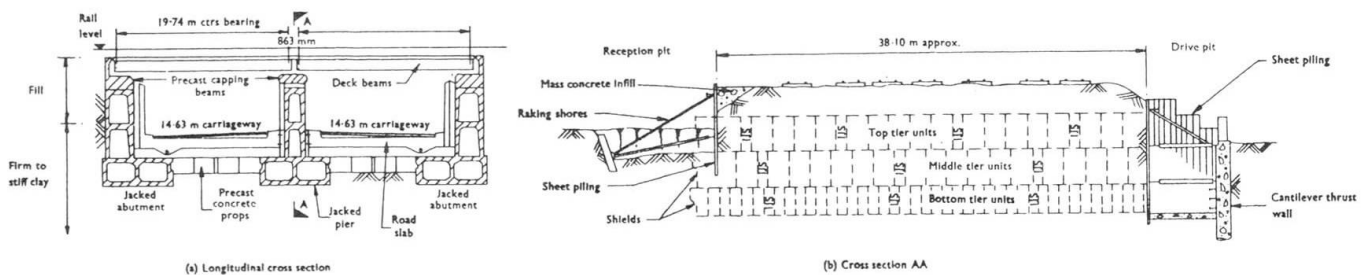


Fig 2 Three tier abutments and piers installed by jacking beneath railway at Old Ford, London

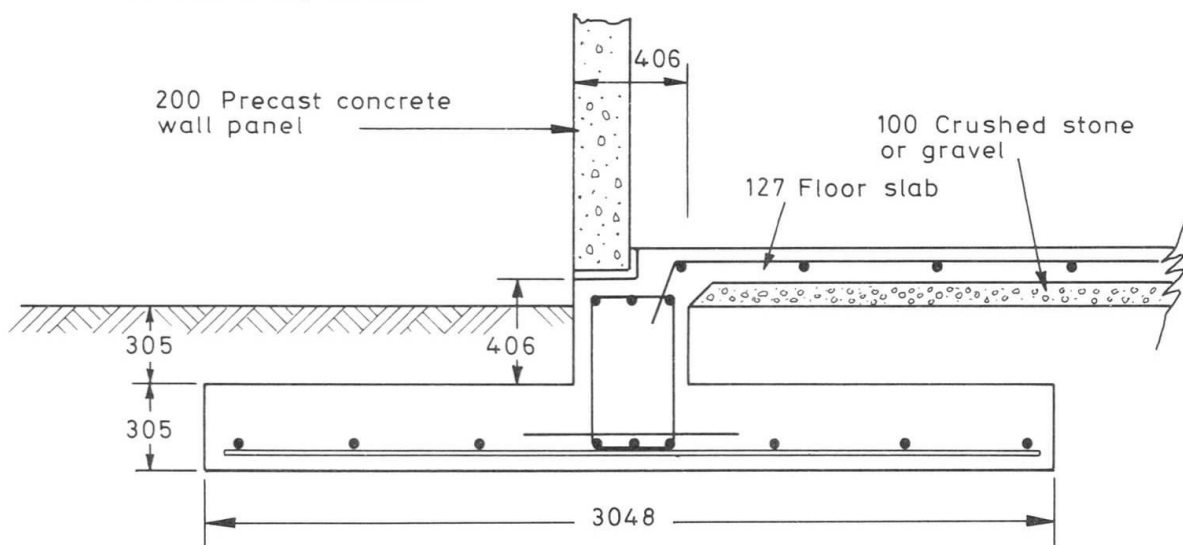


Fig 3 Shallow RC strip foundation for office building on reclaimed swampland at Foster City, California

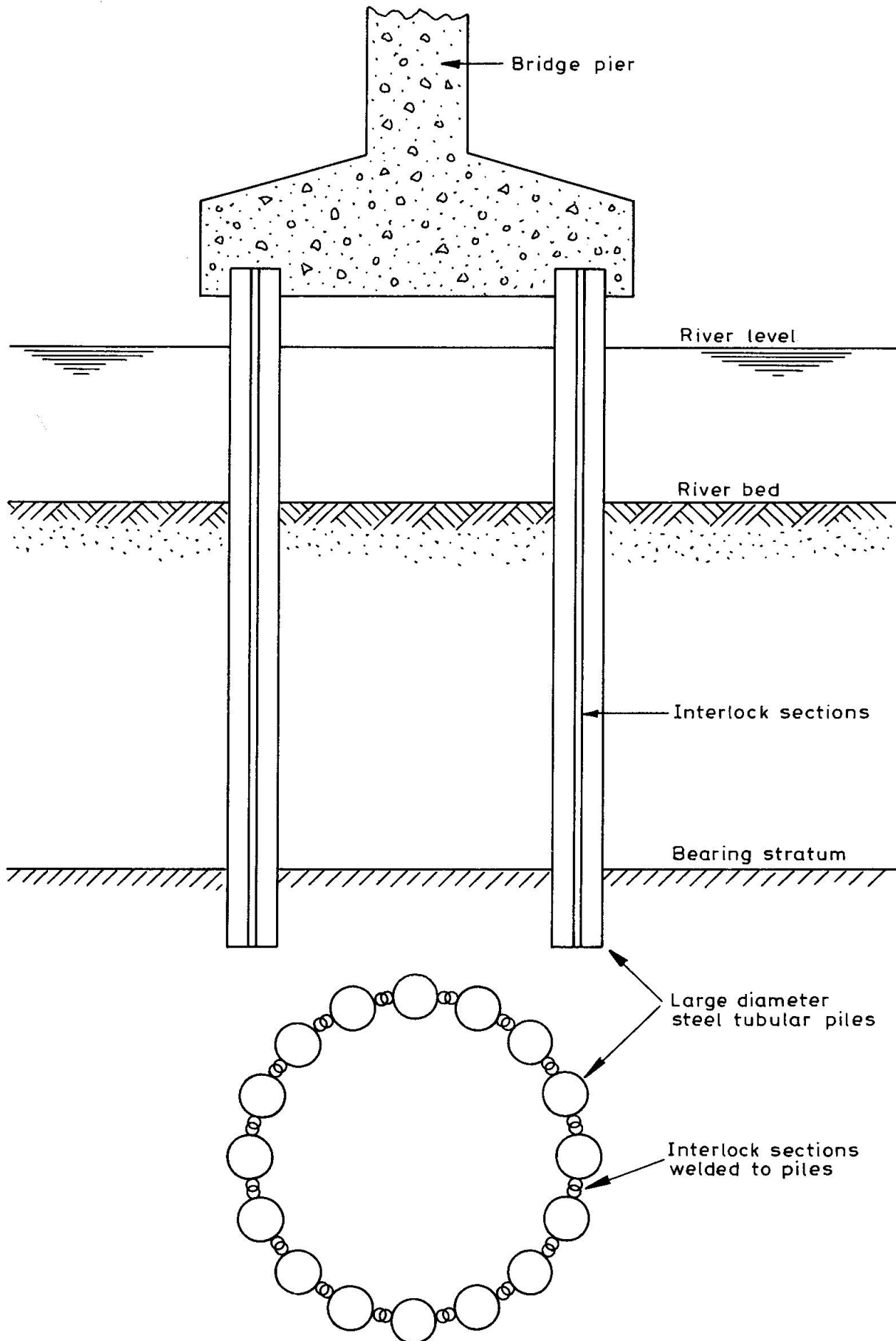


Fig 4 Bridge pier foundations constructed from interlocked steel tubular piles, Japan

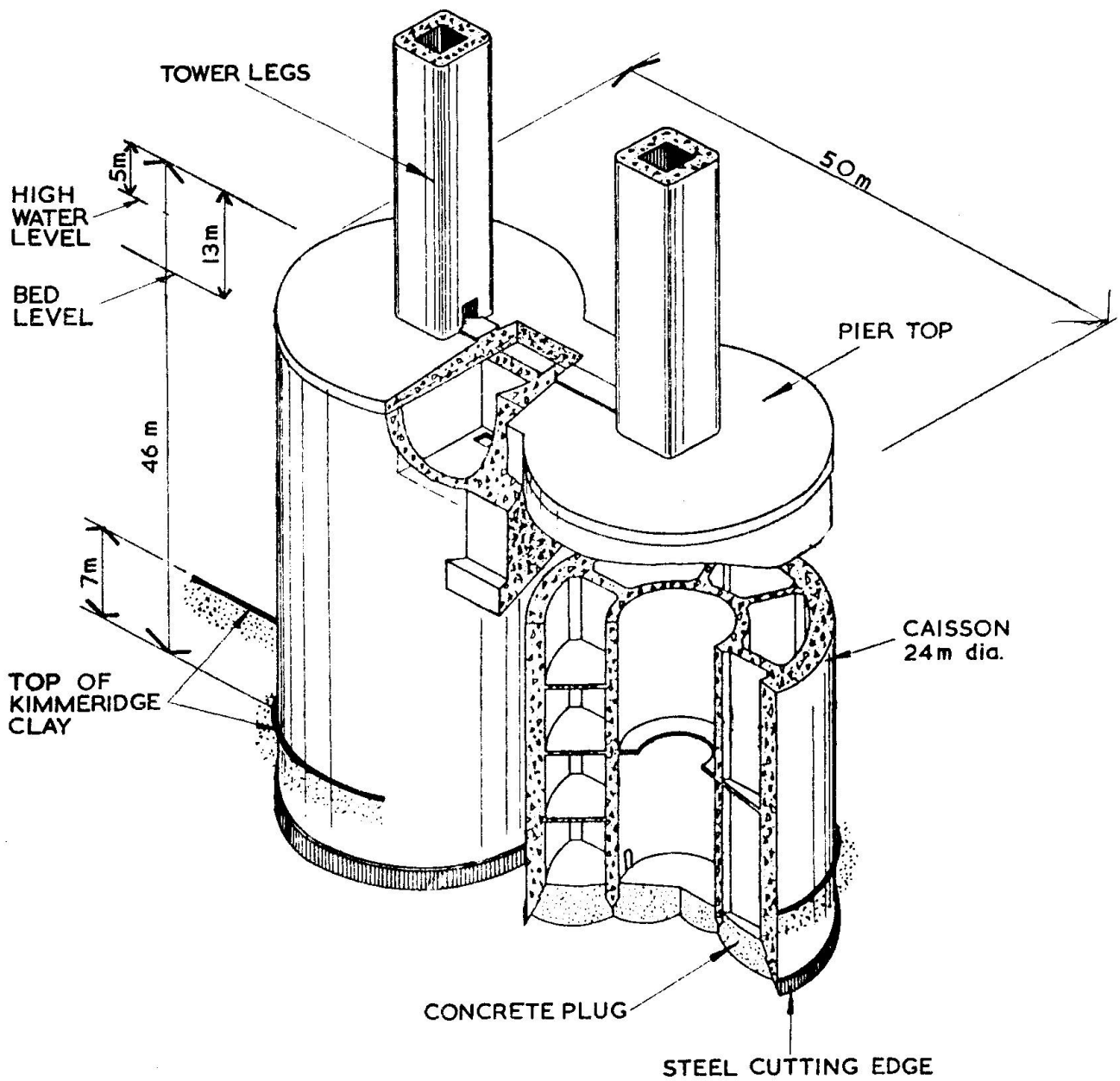


Fig 5 The foundations of the south tower pier, Humber Bridge

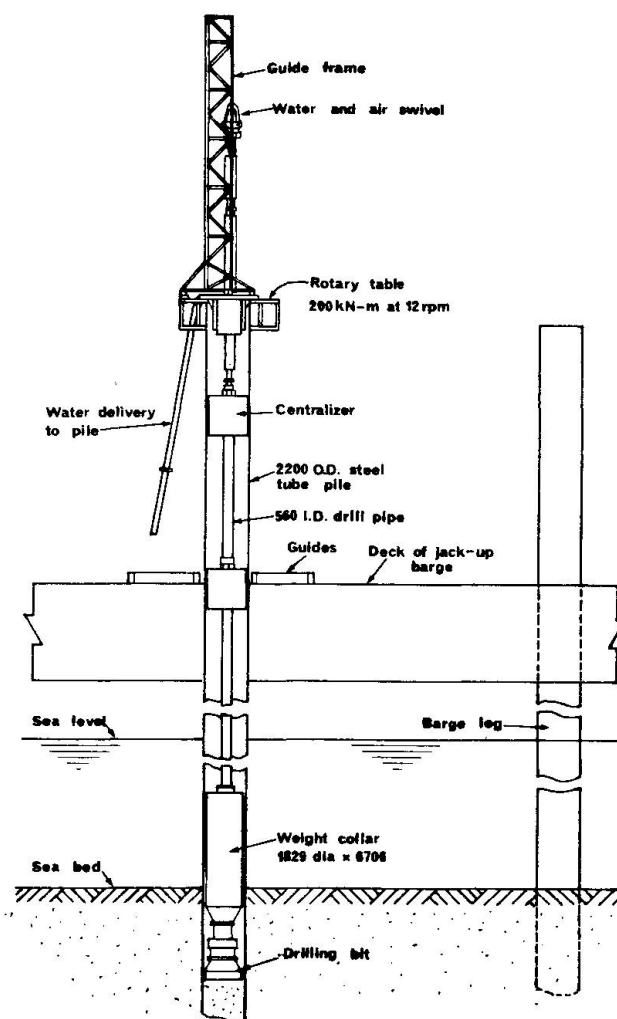


Fig 6 Installing large diameter tubular piles for berthing dolphins, British Petroleum tanker terminal, Firth of Forth



Fig 7 A self-floating petroleum production platform under tow from the construction dock of Brown and Root-Wimpey Highlands Fabricators Limited to the Ninian Field of the Chevron Consortium. The guides for the supporting tubular piles can be seen at each corner of the structure

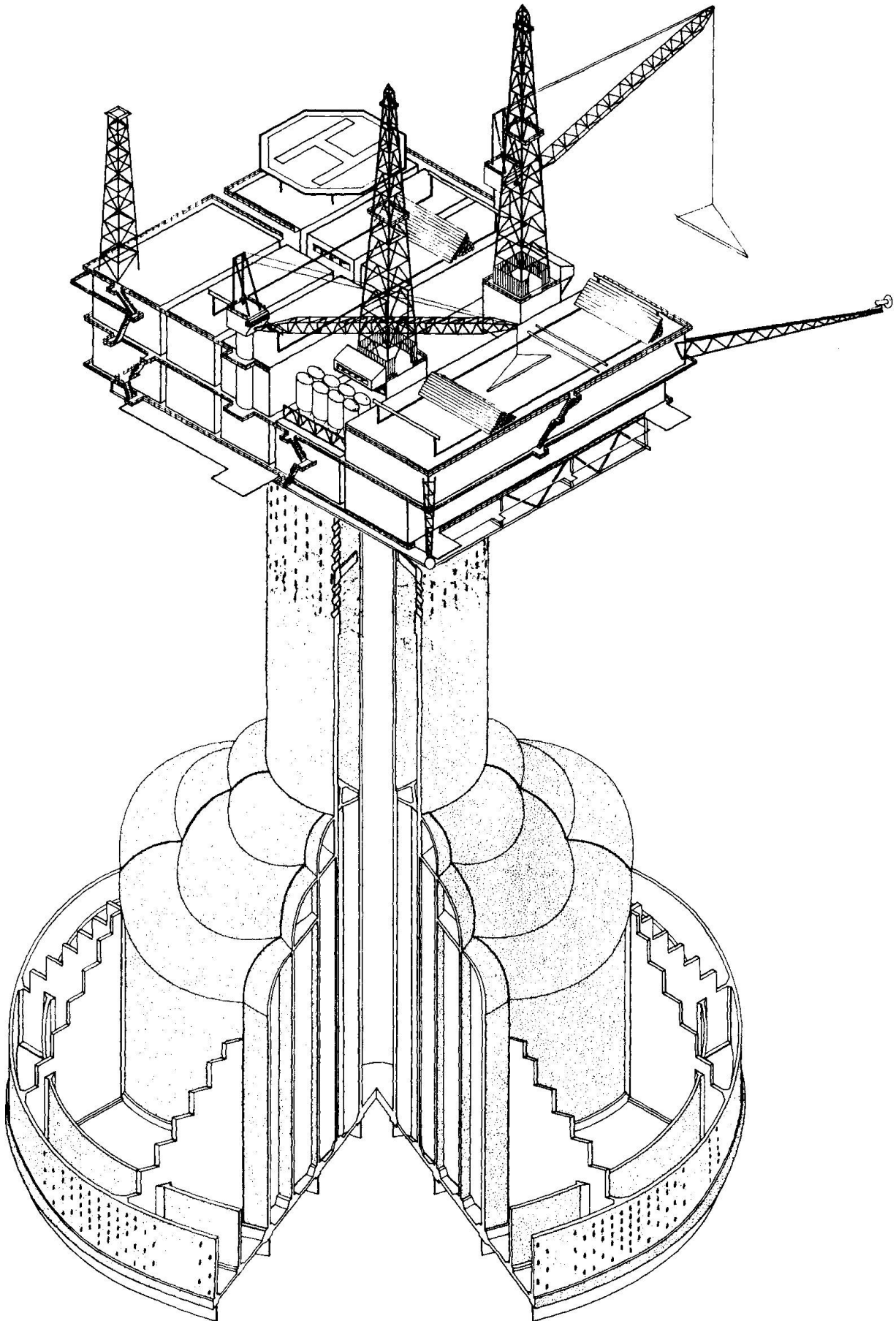


Fig 8 Doris gravity base structure for the Ninian field, North Sea

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