

ANCHORS FOR TENSION PILES:

A COMPARISON OF ACTIVE AND PASSIVE ANCHORS

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INTRODUCTION

Many marine structures jetties and associated works are piled. Wind, wave action, ship berthing and mooring forces, earthquakes, pipe loads etc. can all give rise to upward forces on piles. If these exceed the pile deadweight, a net tension force results. This must be resisted either by bond between the pile & the surrounding ground or by an anchor.

In soils, piled jetties are generally founded on driven piles. Tension capacity is then usually obtained by driving the piles to a suitable depth. Where a hard stratum eg. rock is being encountered before adequate tension capacity is achieved, and piles cannot be driven further, tension capacity is usually obtained by use of an anchor.

This paper addresses the factors involved in selection of the optimum anchor type for a particular project. The methodology is based on a study of experience and published literature. Several sets of series of factors and a method of scoring are proposed, which guide the user to an informed choice of anchor. The authors do not claim it to be the only method. For different sites and structures, different values of the weighting factors may be appropriate.

One of the most important factors in the selection is the individual who makes the choice of anchor type.

This paper is not a design guide for anchors: for that the reader is referred to other standard works such as BS8081, Littlejohn [1977], FIP/2/7, CIRIA R65, etc. However the user should bear in mind that these although excellent design guides were generally written with onshore anchors in mind.

SELECTION OF WEIGHTING FACTORS:

The factors influencing anchor choice can be grouped into the following categories:

- i] Cost
- ii] Basic performance [capacity etc.]
- iii] Long term performance
- iv] Corrosion and durability
- v] General factors e.g. safety.

A contractor will typically seek a optimum 'cost' score, good safety, but will be content with 'acceptable' for the rest ['acceptable' meaning that it conforms with specifications].

A client may well be hoping for excellence in technical factors [ii] to [iv], and only reasonable optimization on cost. The only key aspect for one party is therefore the only non-key factor for the other. Thus, if the Client wants a solution which is technically ideal from his own viewpoint, it is necessary to give a detailed specification, possibly explicitly excluding some undesirable forms of anchor.

PASSIVE ANCHORS

Passive anchors have 2 main sub-types: large diameter and small diameter. Large diameter anchors are those drilled with a diameter of a similar order to that of the pile. They are typically formed of reinforced concrete, have full moment and shear capacity, and act effectively as a bored pile extension to the driven pile. The reinforcement in the concrete is sometimes replaced with a structural steel section. Small diameter anchors are formed in holes drilled with a much smaller diameter than the pile. They have little or no moment capacity at the junction with the pile, and limited shear resistance.

Large diameter anchors have a large surface area per unit length, thus are efficient in weaker rocks where bond strengths [rock to grout] are low, and drilling rates are reasonable. However, for optimum results driven pile penetration must be sufficient to ensure that wedge pull-out of the [usually short] anchor length is not a problem.

Small diameter anchors are more appropriate if anchors have to be drilled to substantial depths below the pile toe. End plates are normally used on the tendons to transfer stress to the base of the anchor, improving the factor of safety against wedge pull-out.

When designing passive anchors for jetties and other piled structures, particular attention has to be paid to the behaviour of the pile tip and its connection to the anchor. Certain types of behaviour should be avoided:

- i] The pile toe should not lose contact with the underlying rock under normal working tension loads. Repetitive lift-off then push down can lead to damage of the anchor-pile connection, loosening and weakening of the nearby rock, and degradation of performance, or even failure. It may be acceptable to allow lift-off under certain extreme events eg. earthquake or emergency shut down [depending on the performance requirements of the structure].
- ii] Rotation of the bottom of the pile must be considered. This is particularly relevant to short pile embedment lengths, where full fixity is not achieved. The designer must assess whether cyclic pile movement will cause progressive weakening/deformation of the rock, leading to unacceptable pile deflections. If the movement is acceptable, the pile/anchor connection must be examined and designed to cope with it. This may be possible using an unbonded length with flexible corrosion protection on the anchor tendons. Cyclic loads and resultant oscillating rotation and flexibility at the

top of the anchor can lead to a tendency for first one side of the pile toe then the other to lift-off under tension loads. Rotation can first be prevented by socketing the piles more deeply or by using a well reinforced large diameter anchor, with sufficient structural strength to transmit horizontal loads down to a greater depth.

- iii] The anchor-pile connection should be such that long-term behaviour will not lead to cracking and corrosion of the anchor bars. This may be guarded against by means of tendon coatings. However, for many passive anchors no protection systems are used. [This is perhaps not unreasonable - who uses corrosion protection on reinforcement in bored pile?]. Corrosion rates below the mudline are very low and the lack of prestress reduces the corrosion susceptibility.

Summaries of the advantages and disadvantages of passive anchors for piles are set out below.

Advantages

- i] Simple, 'low tech' approach.
- ii] Easy to install.
- iii] Cheap materials are used.
- iv] Tendons stop in plug near base of pile, i.e. no need to grout up the entire pile.
- v] No special measures needed for corrosion resistance [e.g. at anchor head].
- vi] No inspections needed.
- vii] Relatively low sensitivity to corrosion.
- viii] Construction is completed in one operation.

Passive Anchors - Disadvantages

- i] Not all individual anchors are proof loaded.
- ii] Rock is unconfined therefore lower bond strength may apply.
- iii] Weak and fractured rocks can be vulnerable to degradation under loads cycling from compression to tension.
- iv] Deformations are required in order to mobilise the anchor capacity.
- v] Inspections are not possible.
- vi] Drilling rates can be very slow and problematic for large diameters.

ACTIVE [PRESTRESSED] ANCHORS

Prestressed anchors have advantages, one of the most important of which is that every anchor is tested during prestressing. Where grouted anchors [as opposed to, for example an anchor wall] are used onshore, these are normally prestressed. [Who would use passive grouted anchors for a retaining wall?]. The question therefore arises "why they should not also be the obvious choice for offshore work?". There are a number of reasons, but they generally fall into two categories: cost and long term reliability.

- The most common reason is cost. Prestressed anchors are frequently more expensive than equivalent passive anchors.
- Many jetties are built on a design and construct basis, and for consultant-designed structures, pile and anchor design is often the Contractor's responsibility. Working

offshore and over water, speed and simplicity of work are vital - floating plant is very expensive. Individual items must often be completed within given tidal or weather windows.

- Another important factor in the use of active anchors is that the prestress forms an extra load on the pile. It must be added to the compressive loads on the pile when designing the pile section against buckling. For short piles this may have little effect, but for large water depths, it can result in expensive increases in pile section, or require the piles to be filled with concrete. [The latter, of course provides a benefit in terms of tendon corrosion protection within the pile.]
- Prestressed anchor tendons are generally brought up to deck level on a jetty. Thus, whereas an entire passive anchor may lie below LAT and below the mud line, parts of active anchors, particularly the anchor heads, are situated in marine environments with potential for high corrosion rates. Provision of access for inspection, maintenance [and, if required, re-stressing] may not be possible, particularly in petrochemical installations.
- Inspection of anchors can be problematic. Specifications typically call for the anchors to be to BS 8081 and/or FIP/2/7 standards. However both of these call for monitoring of stress levels and creep in prestressed anchors for a long period of time, generally for the life of the structure. The authors' experience is that owners do not want to carry out such monitoring, indeed it is often physically impossible to carry it out because anchor heads cease to be accessible, either because they are buried in concrete or because pipelines or other plant is placed immediately above them. For safety, security and for operational reasons many operators, particularly of petrochemical installations, do not want to have contractors working round the jetty pipelines once they are in use.

Summaries of the advantages and disadvantages of prestressed anchors are set out below:

Active Anchors - Advantages

- i] Every anchor is proof loaded during stressing
- ii] Rock is confined thereby giving better bearing capacity/bond.
- iii] Loads do not cycle between tension and compression within the rock.
- iv] Good corrosion protection systems are available.
- v] Only low displacements occur under load.
- vi] If a base plate is used, grout is held in compression therefore there is little risk of cracks and associated corrosion.
- vii] Small diameter holes are required, minimising drilling costs.

Active Anchors - Disadvantages

- i] Extra pile load.
- ii] Relatively complex to install.
- iii] Several stages of installation [install, stress, restress].
- iv] Not as safe to install [stressing hazard].
- v] Tendons are stressed therefore more susceptible to corrosion [and to fatigue].
- vi] Tendons must continue up to deck level for stressing..
- vii] Piles must be fully grouted/concreted to deck level to provide corrosion resistance.

- viii] Demolition [if ever required] is difficult.
- ix] Special skills are needed for installation.

ANCHOR INSTALLATION IN A MARINE SITUATION

In marine works, expensive plant is used and time is a vital consideration. The speed with which the piles can be installed and floating plant moved on to other work is vital to a contractor. Thus the cost of anchor installation are very different from onshore work. Piles must be kept stable in their temporary condition. Support may be necessary to prevent the piles being knocked over by wind, waves, currents and vessel impact until they have their tops fixed into the permanent works. Installing anchors early, particularly large diameter anchors, may reduce or remove the equipment for temporary support. On the other hand, if anchors can be installed from the deck of a jetty, smaller plant may be possible and a major cost saving can result. Prestressing is also much easier from a completed deck. However, this option may not be possible, either because of the construction programme, or where the deck is formed from completed modules, or because no access is available.

Installation costs are also influenced by other requirements of the work. For instance, when a jetty is being piled directly onto rock with little overburden, a minimum pile penetration of several metres will probably be required. The contractor will need a large diameter drill to form sockets to enable piles to reach this minimum penetration. If large diameter anchors are then desired, mobilisation costs are already allowed for, as is the set-up time of the drill at each pile location. It may therefore be cheaper to continue with a large diameter [if drilling rates are reasonable] than to carry out a second operation with a smaller drill. In other locations, it may be that minimum pile penetration can be achieved without drilling, but large anchor depths are required [for wedge pull-out]. In such cases small diameter anchors are preferable.

Thus for every project the costs are dependent on the construction method and programme. Even for a given project, different contractors may have different approaches, resulting in a different cost comparison between anchor types.

Costs of installation, which often form the bulk of the cost of anchors for piled construction, therefore need to be reviewed on a case by case basis. This can best be done in conjunction with an experienced Contractor.

Long term reliability is very important; onshore anchor design usually works on the principle that if any individual anchor fails, the structure must not fail. On a two pile trestle bent, with one tension and one compression pile, or on a 3 or 4 pile dolphin with loads coming from a direction such that only 1 pile has a large tensile load, an anchor failure can be catastrophic.

Active anchors are all proof tested at installation, so initially have a 100% reliability factor. However in the long term they have more potential than passive anchors for loss of reliability [e.g. due to gradual loss of prestress]. Passive anchors, in that they are not all proof loaded, have a lower [although still good] initial reliability. Their simple construction gives them a high long term reliability.

TABLE OF WEIGHTING FACTORS OF ANCHOR TYPE

There are various methods available for drawing up a table of weightings. Importance factors vary with the party involved. In using the tables, or drawing up one's own, it is necessary to identify any key factors which could rule out an anchor type. It is also necessary to understand where items can overlap, to avoid unrepresentative weighting. An example of this is ease of installation aspects. These obviously influence both speed and cost; but less obviously influence safety, reliability [and therefore durability].

In order to use the tables, the authors suggest the following points systems:

- 3 very good
- 2 good
- 1 acceptable
- 0 poor [e.g. awkward, or against advice given in literature]
- 1 Problematic : should be reviewed for necessity and feasibility.

Where an item is not applicable, if this is an advantage, a maximum score should be used, if a disadvantage, an 'acceptable' rating is appropriate [for instance passive anchors score "3" for re-stressing, as they have the benefit of not requiring re-stressing]. The use of -1 to 3 rather than 0 to 4 is because '-1' stands out better in a table.

The tables are filled in for the case of a jetty constructed on ground comprising loose to medium dense sand of limited thickness over moderately weak layered limestone. Fairly typical piles: say 800 mm diameter steel tubes, are assumed with anchors installed prior to deck construction.

Subsection 1 : Cost :

	Item	Prestressed Anchor	Passive Anchor	
			Large Diameter	Small Diameter
1.1	Equipment for installation: mobilisation	2	2	1
1.2	Equipment for installation: running costs	2	2	2
1.3	Pile support requirements	2	1	3
1.4	Time for mobilisation	2	2	2
1.5	Time for installation	2	3	2
1.6	Complexity and/or unproven technique	2	3	3
1.7	Risk of problems with drilling	2	2	2
1.8	Risk of other problems	2	2*	1*
1.9	Programming	2	2	2
1.10	Materials costs : anchors	2	3	3
1.11	Extra pile costs	1	3	2*
TOTAL		21	25	23

* Potential for socketing piles.

Subsection 2 : Basic Performance

	Item	Prestressed Anchor	Passive Anchor	
			Large Diameter	Small Diameter
2.1	Bond in rock	3	3	2
2.2	Certainty of capacity	3	2	1
2.3	Deformation under load	3	3	1
2.4	Maximum capacity	2	3	1
2.5	Pile toe design	2	3	1
2.6	Embedment length: wedge pull-out	3	1	2
TOTAL		16	15	8

Subsection 3 : Long term performance

	Item	Prestressed Anchor	PassiveAnchor	
			Large Diameter	Small Diameter
3.1	Monitoring	-1	3	3
3.2	Grout integrity	2	3	1
3.3	Creep in tendon/anchor	2	3	2
3.4	Creep in rock	3	2	2
3.5	Degradation of rock	3	2	2
3.6	Pile : anchor connection	2	3	1
3.7	Restressing / maintenance	2	3	3
TOTAL		13	19	14

Subsection 4 : Corrosion

	Item	Prestressed Anchor	PassiveAnchor	
			Large Diameter	Small Diameter
4.1	Corrosion susceptibility	2	3	2
4.2	Corrosion protection possible?	2	2	2
4.3	Monitoring	2	2	2
4.4	Effect of cyclic loads on protection.	3	2	1
TOTAL		9	9	7
TOTAL Sections 2, 3 and 4		38	43	29

Subsection 5 : General

	Item	Prestressed Anchor	Passive Anchor	
			Large Diameter	Small Diameter
5.1	Safety during installation	1	2	3
5.2	Compatibility to existing / adjacent structures	3	3	3
5.3	Specific requirements	3+	3+	3+
5.4	Ease of demolition / decommissioning	1	1	2
5.5	Safety of demolition / decommissioning	1	2	2
TOTAL		9	11	13

+ none

Summary

Section	Prestressed Anchor	Passive Anchor	
		Large Diameter	Small Diameter
1	21	25	23
2	16	15	8
3	13	19	14
4	9	9	7
5	9	11	13
TOTAL	68	79	65

The results indicate that a Contractor would probably go for large diameter passive anchors. This is consistent with experience in similar ground conditions. The Contractor in this situation would be unlikely to select prestressed anchors.

A Client, however, might have a preference for large diameter passive anchors, with prestressed anchors as alternative, provided that the inspection and re-stressing issues could be sorted out. The Client would be unlikely to favour small diameter passive anchors, even though they are second choice for the Contractor.

CONCLUSIONS

The paper presents a system which gives a viable basis for selection of anchor types for piles. Selection must be carried out with a clear idea of the objectives if an optimal result is to be achieved.

REFERENCES

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