MECHANICAL JOINTS FOR PRECAST REINFORCED CONCRETE PILES — INTERIM GUIDELINES AND PERFORMANCE SPECIFICATIONS

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SUMMARY

Mechanically jointed precast reinforced concrete piles have been used worldwide for years. There are several types of imported and locally manufactured mechanical joints available in Australia with different capacities offering a range of technical and economical advantages. The performance requirements of the joints vary with their use, particularly in bridgeworks. The paper sets out requirements for mechanical joints intended to be used for piles in bridgeworks. It reviews the design requirements including flexural and tensile capacities, geometric properties embracing play at the joint, limitation of use due to the corrosion potential of soil, testing and sampling. Equations are presented to calculate the required capacities or the number of specimens to be tested for the required confidence level. The techniques of driving of the test specimen and the procedure for a flexural test to calibrate the stiffness of the jointed section are proposed. The conformance of the manufacturer with these requirements will help the designer to select the proper product and will satisfy the requirements for approval of alternatives by the authorities.

In the absence of an Australian standard, the intention is to ensure that the quality of the pile joints and piles are maintained without prolonged approval procedures.

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INTRODUCTION

1. Mechanically jointed piles are used in bridges, buildings and other structures. The obvious benefits are economy, handling and ease of use for long piles.

2. A spliced or jointed pile is loaded differently along its length and this can and should be utilised by a designer. Particularly applicable for long piles, pile segments may be provided with different reinforcement to match the loading requirements or may be of different length hence reducing the cost of transport and driving. The structural resistance of the manufactured joint is subject to change following casting into the pile and during driving. The dilemma facing the designer is what capacity does the mechanically jointed pile have after driving.

3. The selection criteria will vary with the purpose, design life and vulnerability to corrosion. However the selection of wrong or faulty components will result, in most cases, in costly replacements or remedial work.

4. It is considered that the most effective way of determining the appropriateness of a joint is to use a performance based standard or guidelines. However with so many different types of joint and in the absence of an Australian Standard it seems that the task of selecting an appropriate joint type or designing a new one would be very difficult. This paper proposes a methodology, based essentially on the Swedish practices, which should set a benchmark for the assessment of the various joints.

HISTORY

5. Jointed R.C. piles have been used worldwide for years. There are over twenty different types of mechanical pile joints that have been used by the industry in the past two decades. Some of them were developed for a specific project and used with some modification from then on.

6. The evaluation of the joints has been mostly based on performance data that included driving performance, flexural resistance, corrosion resistance, compression and tension. Theoretical analyses have been made, but the author considers that the test data on which these analyses have been conducted are questionable. The data used for evaluation has been mainly submitted by manufacturers to this time and these have generally been favourable. It has been difficult to obtain data reflecting unsatisfactory performance from the manufacturers. Analysis of the joints is even more difficult due to lack of established design criteria.

7. At present the mechanically jointed piles are used as a foundation element throughout the building industry, but with very different requirements for buildings and bridges. A literature search has revealed that only Sweden has formal requirements that specify the necessary performance criteria for a mechanically jointed pile. The current SAA code (AS 2159) states that the joint shall have the same strength as the pile which the author considers a rather vague or at least an impractical and/or uneconomical requirement.
OBJECTIVES

8. As briefly stated above, the principal objectives of this paper are to summarise in a condensed form the requirements that would establish guidelines for manufacturers, assist clients to select a product, reduce the cost of piling directly (number of piles) or indirectly (maintenance) and also maintain the reliability of the product. Metallurgy of the joint is not included in these requirements. With the quality assurance system in place in many companies the author concludes that having a Standard which would embody the entire mechanical joint issue would be a support most welcome by all.

9. VIC ROADS has produced a document "Mechanical joints for precast R.C. piles - VIC ROADS's requirements" with considerable input from the author which could be used as a base for an Australian Standard. The draft document has already been circulated to industry in Victoria with favourable response.

INFLUENCING PHASES AND FACTORS

10. There are three main phases controlling the capacity and performance of the joint when in service as follows:

   (1) Construction of a pile segment with the joint
   (2) Driving of a joined pile
   (3) Corrosion resistance of joints

Phase 1
The most common features that may seriously reduce the capacity of the jointed section are tolerances, squareness and perpendicularity, if not adequately controlled. Proper supervision and/or inspection can overcome this problem.

Phase 2
Driving of the mechanically joined pile will reduce the stiffness of joints (Bredenberg and Broms 1979). The feasible play or gap between the jointing plates should be known and well controlled (e.g. Case-Goble analyser). Excessive play will reduce the capacity of the joint as a result of damage to concrete and also due to heat generated particularly during hard driving (Bredenberg 1982).

Phase 3
Corrosion resistance is a site dependent requirement. Nonetheless without proper site investigation and with regard to the driving technique employed it can become a major factor. Very often it is overlooked that during driving some corrosion protection may be seriously abused hence the design life or capacity would be significantly reduced. The common opinion that without oxygen there is no corrosion is at least misleading because corrosion can also occur in the presence of Sulphate Reducing Bacteria (SRB), when piles are driven through segregated layers containing organic matter or when driven through fill.

11. As the joint is irreversibly going through several stages of degradation the remaining capacity may be only a fraction of the designed or required one. It emerges that
to require the same strength capacity from the jointed segment as from the unspliced pile is rather an impractical and uneconomical requirement or a purely theoretical condition. Consideration must also be given to the flexural stiffness of the jointed section which is undoubtedly influenced mainly by the tolerances of the joint and the driving technique.

The only practical solution that would include all aspects of consideration seems to be the use of factors that would compensate for all unidentified but foreseeable issues. The capacity of a joint is stabilised only after the joined pile is driven. Testing of the ultimate capacity of driven joints would provide valuable data and essential feedback on how to evaluate and factor the capacity of new (undriven) pile joints and will assist in analysis of the joint mechanism.

**DESIGN CRITERIA**

12. The basic design criterion is that the designated service level of the joint should remain unimpaired without corrective action within its design life and should not require routine maintenance for that length of time. The author proposes that the required flexural and tensile capacity of the joint should be such that the joint shall be able to resist the value as follows:

\[
FC = r_1 r_2 Z
\]

but not less than a minimum specified value (kNm)

(From a practical point of view the suggested minimum is 85 kNm for the standard range of precast piles used in bridgeworks)

Where:

\[
FC = \text{the required ultimate flexural capacity of the joint (kNm)}
\]

\[
r_1 = 1.2 \text{ allowance factor for time dependent corrosion and fatigue}
\]

\[
r_2 = \text{factor due to the offset of the joint from the location of maximum bending moment in the joined pile expressed as a ratio of bending moments (Fig. 1)}
\]

\[
0.4 \leq r_2 \leq 1.0
\]
The ultimate design bending moment of the pile (kNm).

and required ultimate tensile capacity \( T \) as:

\[
T = 0.005 A
\]

Where:

\[
\begin{align*}
T & \quad \text{required ultimate tensile capacity (kN)} \\
0.005 & \quad \text{constant} \\
A & \quad \text{cross-sectional area of the pile (mm}^2). \\
\end{align*}
\]

13. The stiffness of the jointed section (\( EI \)), another important criterion, is partly dependent on the joint tolerances, concept (e.g. prestress) and interlocking particulars. The proposed minimum (\( EI \)) value of 2900 kNm² is based on similar requirements in the Swedish practice and the actual stiffness should be determined by testing.

**CORROSION ISSUES**

14. There are four general types of corrosion in soil. These are corrosion in disturbed soil, corrosion in undisturbed soil, bacterial corrosion and corrosion by stray currents. Corrosivity of soil varies with factors like soil resistivity, soil pH and soil chemical content. In general, the corrosion potential of soils should be investigated in all situations.

**Table 1.**

<table>
<thead>
<tr>
<th>Electrical resistance of typical soils *</th>
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<tbody>
<tr>
<td>IGNEOUS ROCKS</td>
</tr>
<tr>
<td>METAMORPHIC ROCKS</td>
</tr>
<tr>
<td>CLAY</td>
</tr>
<tr>
<td>SOFT SHALE</td>
</tr>
<tr>
<td>HARD SHALE</td>
</tr>
<tr>
<td>SAND</td>
</tr>
<tr>
<td>SANDSTONE</td>
</tr>
<tr>
<td>POROUS LIMESTONE</td>
</tr>
<tr>
<td>DENSE LIMESTONE</td>
</tr>
<tr>
<td>( 10^1 )</td>
</tr>
<tr>
<td>( 10^2 )</td>
</tr>
<tr>
<td>( 10^3 )</td>
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<td>( 10^4 )</td>
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<td>( 10^5 )</td>
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<td>( 10^6 )</td>
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<td>( 10^7 )</td>
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<td>( 10^8 )</td>
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</table>

15. The mechanical joints should not be used with precast piles on sites with possible electrolytic action, where minimum soil resistivity, the author proposes, is less than

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175 Ωcm (Table 1. illustrates the range of electrical resistivities of typical soils), on sites with proven occurrence of Sulphate Reducing Bacteria (SRB), or where soils have a pH-value above 9.5 or below 4.0 unless special investigation proves otherwise and/or special protection of a joint is used (Bamber 1979 and Bowles 1984).

**GEOMETRIC PROPERTIES**

16. The shape of the joint should match the cross-section of the precast pile and no part of the joint should extend beyond the surface of the pile. The steel plates, when used, should have sufficient thickness to endure the loads and perform the function of the joint but not be less than 5 mm. The collar (skirt) should have a minimum thickness of 3 mm. To prevent mechanically jointed piles from severe damage particularly during hard driving, the clear axial play of the joint should not exceed a certain specified value during driving. The Canadian Manual of Foundation Engineering suggests, and the author recommends, to adopt 0.5 mm as an upper limit. The out-of-flatness tolerance of the jointing plates of the splice should not exceed 1 in 600 mm in any direction. Except for spun products, two vent holes should be provided in each collar. The holes should be uniformly spaced and located as close to the jointing plates as practical. The preferred diameter of the hole (current experience) is 16 mm. The holes must be uppermost during casting of the pile.

**USE**

17. Generally, the use of mechanical joints should be restricted to an environment substantially free of aggressive ingredients, fluctuating water table and the zone of maximum bending moment in the joined pile. Special attention should be paid to the evaluation of bending moment and the location of the joint particularly in situations where piles are subject to scour and where a pile cap is not used. In stream beds a minimum local scour allowance should be used in addition to the general scour allowance in evaluation of loads and computations (Fig. 2).

**TESTING**

18. Testing of prototypes and established product should be done in a manner that follows recognised statistical rules. It is proposed that the required confidence level should not be less than 95%. The test specimens must be taken from joined piles that have been
driven in the field under controlled conditions. The joint should be perpendicular to the longitudinal axis of the pile segments. When joined, the initial angle change of the axis of the pile at the joint should be less than 1:300.

19. Sampling, with exception of prototypes, should be done in accordance with the appropriate Australian Standard (e.g. AS 1199). The test specimens must be clearly marked. The number of specimens \( n \) which should be tested for the required confidence level must follow recognised statistical rules.

20. As testing is rather expensive, it is desirable to adopt a method that would permit a manufacturer to benefit from controlled operational procedures in place, consequently reduced variation and controlled standard deviation, with respect to the number of samples required. The following statistical approach is proposed.

\[
n = \left( \frac{t_{\alpha} \nu}{r} \right)^2, \text{ but not less than 2}
\]

Where:

- \( t_{\alpha} \) = constant (value of Student’s \( t \)) which depends on \( n \) and confidence level \( \psi \) (refer to a text book on statistics)
- \( \alpha \) = risk;
- \( \alpha = \left( 1 - \frac{\psi}{100} \right) \)
- \( r \) = Specified limit of variation in percent.

Where: \( r = 10 \) Tensile testing
\( r = 20 \) Flexural testing

(Rationalised values based on author’s judgement)

\( \nu \) = coefficient of variation in percent

\[
\nu = \frac{100 s}{\bar{x}}
\]

Where: \( \bar{x} \) = mean value of the test results \( x_i \)

\[
\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}
\]

\( s \) = standard deviation

\[
s = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n - 1}}
\]
The flexural or tensile capacity $C_{\text{Test}}$ of the joint shall be calculated from the test results as $C_{\text{Test}} = \bar{x}_{\text{Test}} - t_a s_{\text{Test}}$ where $\bar{x}$, $t_a$, and $s$ are as defined above and the subscript distinguishes between flexural and tensile test and $C_{\text{Test}} \geq FC$. Alternatively, the method as described in AS 4100 Chapter 17 - Testing could be used. However using the latter the reduction in allowable joint capacity seems to be rather substantial without any gain due to controlled procedures.

**DRIVING OF THE TEST SPECIMEN**

21. The driving should be carried out at a place where rock level has been confirmed by geotechnical investigation or by other means. From the testing point of view, refusal should occur at a depth of 3 to 5 m below the ground surface. The bottom pile element fitted with a rock shoe must have such a length that the joint shall be located above the ground during driving at all times. The length of the top pile element should not be less than 3 m. The pile shall be joined after the bottom pile element has been driven to refusal against the rock.

22. The jointing plane must be perpendicular to the longitudinal axis of the pile element. When joined, the initial angle change at the joint should be less than 1:300. The joint shall be subjected to at least 2500 blows by a 3 ton drop hammer at a height of fall of 300 mm and to 500 blows at a height of fall of 400 mm. The joint should be checked and inspected every 500 blows. The maximum allowable angle change at the joint shall not exceed 1:75. The joint should be able to withstand the stresses during driving without any obvious sign of distress. The procedure has been calibrated by and is being used by the Swedish Board of Physical Planning and Building and is considered appropriate.

**PROCEDURE FOR FLEXURAL AND TENSILE TEST**

**FLEXURAL TEST**

23. The test specimen (refer 18. Testing) approximately 3 m long, shall be loaded by two equal loads at the third points (Fig. 3). Those test specimens which are apparently deformed should be placed on supports in such a way that they shall deviate either upwards or downwards in the direction of loading.

24. The loads must be applied simultaneously at both locations in at least ten increments until failure. The load during each increment should be maintained for at least 3 minutes. The deflection shall be measured at the centre of the pile at the joint and relative to the two reference points located 700 mm each side of the joint centreline. The first readings shall be made when the test specimen is loaded only by its self weight (zero-readings). The stiffness shall be calculated from the equation:

$$EI = \frac{M L^2}{8 d}$$
Where:

\[ EI = \text{stiffness (kNm}^2) \]
\[ L = \text{distance between the two reference points (m)} \]
\[ M = \text{ultimate moment at the joint in the constant moment region (kNm)} \]
\[ d = \text{deflection within L distance (m)} \]
\[ 8 = \text{constant (refers to testing set-up as shown in (Fig. 3) and may be changed for a different set-up).} \]

**Flexural test arrangement**

![Diagram of flexural test arrangement](image)

**Fig. 3**

**TENSILE TEST**

25. The test specimen (refer 18. Testing) shall be tested in pure tension until failure. The load should be applied in controlled manner and at uniform rate (Fig. 4).

**BENEFITS**

26. Certifying the capacity of mechanical pile joint will reduce lengthy approval procedures, save time for tenderers and will help to utilise foundation and substructure to their full potential, for instance in joint-less bridges or in structures with high lateral loads. The associated cost benefits are apparent for new structures and maintenance of existing
structures. It is considered by the author that written requirements for pile joints should encourage innovation and competition leading to cost effective designs and cheaper components of high quality. Quality control and procedures are simply unthinkable without precise definition. There are market opportunities for mechanical joints worldwide and the author believes that an Australian Standard would help to foster innovation and creation of new product (mechanical joint) for export.

CONCLUSION

27. It would be highly desirable to have an Australian Standard that would clearly stipulate requirements for mechanical pile joints and with national application. Meanwhile this paper is practically oriented to professional engineers and implementation of proposed methods would put an end to the discrepancies in approval procedures and would positively contribute to the further implementation of quality assurance by manufacturers, suppliers and by the industry in whole, in the absence of an Australian Standard. The conformance of the manufacturer with the requirements will help designers to select the proper product and will satisfy the requirements for approval of alternatives by the authorities.
REFERENCES


