Comparison between Chinese and British Standards for Strand Anchor Structure Design

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Abstract: In this paper, the relevant provisions regarding the classification, safety factor, strand anchor structure design and corrosion protection design are compared between the British standard BS EN 1537:2013, BS 08081:2015 and the Chinese national standard GB 50086-2015, the main differences of the strand anchor design are summarized, which can be used as reference for other strand anchor designers and researchers.

1. Introduction
With the development of The Belt and Road plan, more and more Chinese enterprises are participating in the design and construction of oversea projects. The proper understanding of international standards is particularly important for the success of projects. At present, there are few comparative analyses on the structural design of strand anchor. During the design process of an oversea project that the author participated in, it was found that the relevant specifications of the design and construction of strand anchor structure in Chinese and British standards are quite different, so the previous design based on Chinese standards should not be adopted directly in the oversea project. The main British standards regarding the design of strand anchor are BS EN 1537:2013 Execution of special geotechnical works-ground anchors[1], which specifies the implementation, testing and monitoring of tendon, and BS 08081:2015 Code of practice for grouted anchors[2], which specifies the structure design, ultimate resistance and implementation of strand anchor. Chinese national standard GB 50086-2015 Technical code for engineering of ground anchorages and shotcrete support[3], which specifies the types, material, corrosion protection, design and construction of strand anchor. The purpose of this paper is to compare the similarities and differences between the British standards BS EN 1537:2013, BS08081:2015 and Chinese national standard GB 50086-2015 in strand anchor design.

2. Classification of strand anchor
If anchors are classified by the designed service life, BS EN 1537 defines the anchor with a designed service life of more than 2 years as permanent anchor, and the anchor with a designed service life of less than 2 years as temporary anchor, which is the same as the definition in GB 50086.

If anchors are classified by anchoring characteristics, BS 08081 divides the anchor into four types: A, B, C and D, see figure 1. Type A anchors feature tremie- (gravity displacement-), packer- or cartridge-grouted, straight shaft boreholes, which may be temporarily lined or unlined depending on borehole stability. Type B anchors feature low-pressure (typically, grout injection pressure at p<1000 kPa)
grouted boreholes, grouted via a lining tube or in situ packer, where the diameter of the fixed anchor is increased with minimal disturbance as the grout permeates through the pores or natural fractures of the ground. Type C anchors feature boreholes grouted to high pressure (typically, $p_i > 2000$ kPa), via a lining tube or in situ packer. The fixed anchor length is enlarged by hydrofracturing of the ground mass to give a grout root or fissure system beyond the core diameter of the borehole. Type D anchors feature tremie-grouted boreholes, in which a series of enlargements, either bells or underreams, have previously been formed.

GB 50086 divides anchors into three types: the first type is tension type and compression type; the second type is compression-dispersed type and tension-dispersed type; the third type is post (repeat) high pressure grouting type anchor and removable type anchor.

Although the classification standards are different and the types are varied, the most widely used type A anchor or tension type anchor is simple in structure and convenient in construction.

Figure 1. 1: A type  2: B type  3: C type  4: D type

3. Safety factors

3.1 Utilization coefficient of strands
The strand anchor is generally composed of several prestressing strands. In the actual production and implementation process, the force unevenness of prestressing strands varies greatly. At the same time, if the ground is aggressive, the corrosion protection of strands is not well guaranteed, and the corrosion of strands will also lead to the decrease of tensile strength. For the utilization coefficient of prestressing strands, Chinese standard has made the different utilization coefficient of strands for permanent and temporary strand anchor, while BS 08081 has not made a distinction.

Regarding the utilization coefficient of strands, BS 08081 §11.3.5 specifies:

$$R_{T,d} \geq \max (F_{ULS,d}; P_p) \quad \text{and} \quad F_{Serv;k} \leq \frac{R_{T,d}}{\gamma_T}$$

where,

$$R_{T,d} = \frac{R_{T,k}}{\gamma_s} \quad R_{T,k} \leq 0.80 f_{pk} A \quad R_{T,d} \quad \text{is the ultimate limit state design resistance of the structural elements of an anchor, } F_{ULS,d} \text{ is the design value of the force required to prevent any ultimate limit state in the supported structure, } P_p \text{ is proof load, } \gamma_T \text{ is equal to } 2.0 \text{(as per BS 08081 Table 2), } \gamma_s$$
is the partial factor for prestressing steel, 1.15 (as per BS EN 1992-1-1:2004[4] table 2.1N), $f_{pk}$ is the characteristic tensile strength of tendon. $F_{\text{Servk}}$ is the characteristic value of the maximum anchor force, including effect of lock-off load, however it is acceptable to adopt that $T_w$ approximates to the maximum characteristic anchor force $F_{\text{Servk}}$. So, the actual utilization coefficient of strand is about 0.35.

GB 50086 §4.6 specifies:

$$N_d \leq f_{py} \cdot A_s$$

(2)

Where, $N_d$ is the designed anchor force, $f_{py}$ is the designed tensile strength of tendon, $A_s$ is the cross-section area of strands. According to GB 50010-2010(2015)[5] Table 4.2.3-2, the ratio of $f_{py}$ and $f_{ptk}$ is about 0.71. In addition, the tensile controlled maximum stress of strands shall also be met, that is: for permanent anchor, the controlled maximum stress $\sigma_{\text{con}} \leq 0.55f_{ptk}$, i.e., the utilization coefficient of strands is 0.55; for temporary anchor, the utilization coefficient of strands is 0.65. It can be concluded that the British standard is more conservative.

3.2 Resistance factors of fixed length

The design of the fixed length of the strand anchor normally needs to consider the interface resistance of grout/tendon and ground/grout. But if the ground is aggressive, and the encapsulation is adopted in the anchor design, the interface resistance of grout/encapsulation also needs to be considered. BS 08081 specifies the minimum resistance factors of interface resistance of grout/tendon, grout/encapsulation and ground/grout as 3.0. However, it can be adjusted according to different situations, such as: minimum resistance factors for the ground/grout interface generally lie between 2.5 and 4.0. However, these may vary, where investigation tests provide sufficient additional information to permit a reduction. The typical calculation formula of fixed length is as follows:

$$F_{\text{Servk}} \leq \frac{R_{G,k}}{\gamma}, \quad F_{UL,S,d} \leq R_{G,k}$$

(3)

where, $R_{G,k}$ is the characteristic ultimate interface resistance, $\gamma$ is the safety factor.

GB 50086 §4.6 specifies the ground/grout and grout/strands resistance factor, and the resistance factor of ground/grout also distinguishes the permanent/temporary anchor and the project grade. For the resistance factor of grout/strands, only an interface bond strength reduction factor $\xi (=0.70–0.85)$ is considered, that is, the corresponding resistance factor of grout/strands is 1.18–1.43. The fixed length can be calculated as follows.

$$N_d \leq f_{mg} \cdot \frac{\pi \cdot D \cdot L_a \cdot \psi}{K}$$

(4)

Grout and ground:

$$N_d \leq f_{ms} \cdot n \cdot \pi \cdot d \cdot L_u \cdot \xi$$

(5)

Grout and strands:

where, $L_a$ is the fixed length; $f_{mg}$ is the characteristic ultimate ground/grout interface resistance in fixed length; $f_{ms}$ is the designed ultimate grout/strands interface resistance in fixed length; $D$ is the borehole diameter of fixed length; $d$ is the diameter of strand; $K$ is the bond resistance factor of ground/grout interface in fixed length; $\xi$ is the interface bond strength reduction factor when 2 or more strands are adopted, taken as 0.70–0.85; $\psi$ is the ultimate resistance influence coefficient in fixed length; $n$ is the number of strands. The comparison of resistance factors between BS 08081 and GB 50086 is shown in Table 1.

| Table 1. The resistance factors of BS 08081 and GB 50086 |
|----------------------------------------------------------|
| Code | BS 08081 | GB 50086 |
|------|----------|----------|
| Ground/grout | 2.2(permanent) | 1.8(temporary) |
| Grout/strands | | |

3
It can be concluded that, British standard specifies the higher resistance factors of fixed length than Chinese standard. In addition, British standard also specifies the resistance factor for ultimate grout/encapsulation interface resistance. The resistance factor of ultimate grout/tendon interface resistance of GB 50086 is relatively low (although $f_{\text{ms}}$ is the designed ultimate grout/strands interface resistance). So, it is necessary to consider the condition that the grout is not properly compacted and the stress of each strand is unequal, a higher resistance factor of ultimate grout/tendon interface resistance is suggested (although GB 50086 distinguishes the type of permanent and temporary strand anchors, and the interface resistance of permanent strand anchor is greater than the corresponding temporary strand anchor, but it is not appropriate to consider it as the safety factor).

4. Specification for strand anchor design

4.1 Anchor arrangement
To ensure the fixed length can be fully grouted, both BS EN 1537 and GB 50086 specify the anchor inclinations should be larger than 10°, if this is not possible, the countermeasures shall be carried out. Both BS EN 1997-1[6] and GB 50086 specify the minimum spacing of fixed length shall be 1.5m. BS 08081 specifies the minimum spacing shall not be less than 4 times the maximum diameter of the fixed anchor to limit the interaction, generally not less than 1.5m~2m; the distance between a fixed anchor and an adjacent foundation or underground service should be at least 3 m. GB 50086 specifies that the anchor arrangement should be diamond or rectangular, and the spacing should not be greater than 1/2 of the length of the anchor.

4.2 Selection of strand
The material and component quality of the strand are related to the stability and durability of the strand anchor, it is very important to select the right type of strand. The prestressed strand used in the anchor based on the European standard can be selected by referring to table 2 of prEN 10138-3[7]. Generally, GB/T 5224-2014[8] is used for selection based on Chinese standards. Due to the different standards, the mechanical properties of prestressing strand with the same diameter and structure are different.

4.3 Anchor head
BS EN 1537, BS 08081 and GB 50086 do not specify a minimum thickness for bearing plate, but specify that the bearing plate shall be designed according to the designed force. The thickness of bearing plate based on European standard can be calculated as per European standard BS EN1993-1-1[9]. BS EN 1537 specifies that steel caps for permanent strand anchor shall have a minimum wall thickness of 3mm; reinforced plastic caps shall have a minimum flange thickness of 10 mm and a minimum wall thickness of 5 mm.

4.4 Fixed length
BS 08081 specifies, for cement or resin grouted anchors, the bond length should be not less than 3 m where the tendon is homed and bonded in situ; and 2 m where the tendon is bonded under factory controlled conditions, unless full-scale tests confirm that shorter bond lengths are acceptable, but normally should be less than 10m. The above values are based on a minimum grout compressive strength of 30 MPa prior to stressing. These values can be applied to single unit tendons and to parallel, multi-unit tendons, provided that the clear spacing is not less than 5 mm. GB 50086 specifies, the fixed length of the anchor shall comply with the following provisions, depending on the ground conditions: the fixed length of tension/compression type anchor should be 3m~8m(rock) and 6m~12m(soil). the unit fixed

| factor          | 3  | 2.0(permanent) | 1.6(temporary) | 1.18~1.43 | 2.0(permanent) | 1.5(temporary) |
|-----------------|----|----------------|----------------|-----------|----------------|----------------|


The length of tension-dispersed/compression-dispersed type anchor should be 2m–3m (rock) and 3m–6m (soil).

4.5 Free length
BS 08081 specifies, a minimum free anchor length of 5 m should be used for strand anchors, as an additional extension should be available to allow for wedge draw.

GB 50086 specifies that the length of the free length of the anchor through the potential sliding crack surface shall not be less than 1.5 m. The length of the free length of the anchor shall not be less than 5.0 m, and the overall stability of the anchor and the anchored structure system shall be guaranteed.

4.6 Other components
The suggested distance of centralizer is 1.0 m–3.0 m by BS 08081, but which is controlled by stiffness of encapsulation. GB 50086 specifies, the spacing between the spacer/centralizer shall not be more than 2 m. In addition, the spacer/centralizer shall be made of steel, plastic or other materials harmless to the tendon body and grouting body.

BS EN 1537 also specifies that the minimum wall thickness of an external corrugated duct common to one or several tendon elements shall be: 1.0 mm for internal diameter ≤ 80 mm; 1.2 mm for internal diameter > 80 mm but ≤ 120 mm; 1.5 mm for internal diameter > 120 mm. The minimum wall thickness of an external smooth common sheath or duct shall be 1 mm greater than that required for the corrugated ducts, or it shall be reinforced. The minimum wall thickness of an internal sheath and an internal corrugated duct shall be 1.0 mm. The wall thickness of the sleeve after shrinkage shall be not less than 1 mm. The minimum overlap shall not be less than 50 mm.

5. Corrosion protection design
The long-term effective operation of the anchorage system is of great significance to the safety and stability of the supported structures. The corrosion types of prestressed anchor mainly include chemical corrosion, electrostatic corrosion and stress corrosion, the corrosion of strand will lead to the reduction of effective section, that is, the reduction of effective resistance, the corrosion of anchor head may lead to the loss of prestress. With the deepening of the understanding of the corrosion protection of strand anchor, the corresponding regulations on prestressed anchor corrosion protection are becoming more and more specific and strict.

5.1 Definition of corrosion protection
BS EN 1537 specifies that the aggressivity of the environment shall be defined in accordance with BS EN 206-1 [10].

BS 08081 Table E.1 provides the ground aggressivity judgment criteria.

| Soil corrosiveness | Soil resistivity | Redox potential (corrected to PH=7) |
|--------------------|-----------------|-------------------------------------|
|                    | Ω-cm            | mV                                  |
| Very corrosive     | <700            | <100                                |
| Ascorrosive        | 700–2000        | 100–200                             |
| Moderately corrosive| 2000–5000      | 200–400                             |
| Mildly corrosive or non-corrosive| >5000| >430 if clay soil                    |

GB 50086 does not classify the grade of corrosion, specifies that, when one or more of the following conditions exist in the detection and investigation of the ground, the ground shall be judged to be corrosive:

1. pH < 4.5;
2. Electrical resistivity < 2000 Ω·cm;
3. Sulfide;
4 stray current or chemical corrosion affecting grout and tendon.

5.2 Corrosion protection design

BS EN 1537 specifies, all steel components shall be protected against corrosion for their designed service life. All installed tendons and encapsulations shall be provided with a minimum of 10 mm grout cover within the fixed length.

For temporary ground anchor, the corrosion protection shall be adopted if the ground is aggressive.

For permanent ground anchor, at least a single corrosion protection shall be adopted, and the corrosion preventive material shall not degrade during its designed service life. The corrosion protection system shall comprise either:

a) a single protective barrier to corrosion, the integrity of which shall be proven by testing each anchor in situ unless otherwise specified; or

b) two protective barriers to corrosion such, that if one barrier is damaged during installation or anchor loading, the second barrier remains intact.

The typical examples of single and double corrosion protection for the tendon are shown in figure 2.
Table 3. The requirements of grade I, II, III of anticorrosion protection design

| Grade type                        | Anti-corrosion measures Anchor head | Free length                                      | Fixed length                   |
|-----------------------------------|-------------------------------------|--------------------------------------------------|--------------------------------|
| I                                 | Tension type, tension-dispersed type | Adopt transition pipe, anchorage is protected by concrete or steel cap | Adopt protective pipe/unbonded strand, inject grease and cover with smooth sheath | Adopt encapsulation, inject grout |
| Compression type, compression-dispersed type | | Adopt transition pipe, anchorage is protected by concrete or steel cap | Adopt unbonded strand, inject grease and cover with smooth sheath | Adopt unbonded strand |
| II                                | Tension type, tension-dispersed type | Adopt transition pipe, anchorage is protected by concrete or steel cap | Adopt protective pipe/unbonded strand, inject grease | Adopt encapsulation, inject grout |
| Compression type, compression-dispersed type | | Adopt transition pipe, anchorage is protected by concrete or steel cap | Adopt unbonded strand | Adopt unbonded strand |
| III                               | Tension type, tension-dispersed type | Adopt transition pipe, anchorage is protected by grease | Adopt protective pipe/unbonded strand, inject grease | inject grout |

It can be concluded, both BS EN 1537 and BS 08081 specify that the strand anchor are required to be protected with encapsulation in aggressive ground. Although BS EN 1537 specifies, the internal cement grout can be adopted as a protective barrier when it can be ensured that the crack in the encapsulation under the service loading is no exceed 0.1mm. However, in general, the permanent anchor needs to be designed with a double corrosion protection, because the strand does not have the thread like the bar, and the continuous increase of the strain of the strand cannot guarantee the crack control. The outer cement grout (between encapsulation and ground) is not considered as a protective barrier by BS EN 1537 and BS 08081, since it is difficult to verify the integrity during designed service life. The Chinese standard does not specify the limitation of the crack in cement grout, the cement grout outside or inside the encapsulation is not distinguished as well, which is seen as a protective barrier.

BS EN 1537 specifies, cement grout injected into boreholes is permitted as temporary corrosion protection in a non-aggressive environment, provided that the cover to the tendon is not less than 10 mm throughout its length.

For permanent tendon, cement grout in accordance with EN 447 injected under factory (or equivalent) controlled conditions is permitted as one of the two permanent protection barriers, provided that the cover between the tendon and the outer barrier is not less than 5 mm. A minimum 5mm of resin grouts cover to the tendon injected or placed in a controlled manner are permitted as one permanent barrier providing they are contained, and when stressed do not crack.

GB 50086 specifies, the thickness of grout shall be not less than 20mm in grade I and II anticorrosion protection design; the thickness of grout shall be not less than 10mm in grade III anticorrosion protection design.

GB 50086 specifies that the permanent anchor shall be protected from corrosion by relevant parts of the anchor head after the completion of tension operation; if the prestress of tendon need to be adjusted in the future, a metal cap filling with corrosion protection compound shall be adopted for the corrosion protection of anchor head; if the prestress does not need to be adjusted, the anchorage, bearing plate and tendon end of the permanent tendon can be protected by concrete, and the thickness of concrete should not be less than 50mm. The above requirements are similar with BS EN 1537, but for the latter one, a rigid plastic cap and resin can be adopted as well.
6. Conclusion

In this paper, the following conclusions can be drawn from the comparative analysis of the provisions on prestressed strand anchor design of BS EN 1537 BS 08081 and GB 50086.

1) If anchors are classified by the designed service life, BS EN 1537 defines the anchor with a designed service life of more than 2 years as permanent anchor, and the anchor with a designed service life of less than 2 years as temporary anchor, which is the same as the definition in GB 50086.

   If anchors are classified by anchoring characteristics, Chinese standard classifies the anchor by load-carrying type, Britain standard classifies the anchor by the borehole shape.

2) British standard specifies a lower utilization coefficient of strands than Chinese standard. For resistance factors of fixed length, British standard is more conservative than Chinese standard as well. In addition, British standard specifies the resistance factor of ultimate grout/encapsulation interface resistance. Due to the uneven force in strands and in case of aggressive ground, it is recommended to adopt a higher resistance factor when designing the strand anchor as per GB 50086.

3) There is little difference between British standard and the Chinese standard in terms of the design of strand anchor structure, but British standard is more detailed.

4) British standard specifies that at least a single corrosion barrier is required in aggressive ground; generally, a double corrosion barrier is required for permanent strand anchor. GB 50086 also specifies the protection of different types of anchors in detail, but does not consider the impact of grouting cracking on the anti-corrosion performance. British standard also provides the detailed provisions of anti-corrosion material components.

References

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[2] BS 08081:2015, Code of practice for grouted anchors[S].
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