# Design and analysis of bridge foundation with different codes 

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#### Abstract

This paper discussed the design and analysis of bridge foundation subjected to load of train with four codes, namely AASHTO code, British Standard BS Code 8004 (1986), The Chinese National Standard (CNS, 2002) and Chinese code (TB10002.5-2005). The study focused on the design and analysis of bridge's foundation manually with the four codes and found which code is better for design and controls the problem of high settlement due to the applied loads. The results showed the Chinese codes are costly that the number of reinforcement bars in the pile cap and piles is more than those with AASHTO code and BS code with the same dimensions. Settlement of the bridge was calculated depending on the data collected from the project site. The vertical ultimate bearing capacity of single pile for three codes was also discussed. Another analysis by using the three-dimensional Plaxis program of finite elements and many parameters were calculated. The maximum values of the vertical displacement were close to the calculated ones. The results indicate that the AASHTO code was economics and safer in the bearing capacity of single pile, while the Chinese code (CNS, 2002) gave a good indicator of the risk to foundation settlement.


Key word: Bridge engineering, settlement and bearing capacity, codes for design.

## INTRODUCTION

There are many codes used around the world and most of countries have their own code depending on the nature of them and the surrounding circumstances, such as the effect of earthquakes and heavy snowfall, etc. In the United States, Bridge Engineers use the code of AASHTO namely "American Association of State Highway and Transportation Officials"; this code can be adopted for design of the high speed rail way bridges with special requirements. In similar fashion or trends, German bridge engineers utilize the DIN standard and British engineers use the BS 5400-2 (1978) "British Standard" code to do the design.
In general, countries like German and United Kingdom have developed major highway and railway systems for many years and they possess their own national bridge standards. The AASHTO Standard Specification, however, have been accepted by many countries as the general code by which bridges should be designed (Wan and Wan, 2005). In China, there are many codes

[^0]about 81 codes for design in all the fields of the civil engineering with serial numbers of standard.
For the same project, the results of design with different codes may not be consistent. In order to choose the most appropriate one, it is necessary to do an analysis of comparison of the results with different codes.
In this study, four codes will be adopted for the analysis, that is:

1. AASHTO-LRFD Bridge Design Specifications.
2. British Standard 5400-2.
3. The Chinese National Standard (CNS, 2002) (GB50007-2002).
4. TB 10002.5-2005/J 464-2005, Code for Design on Subsoil and Foundation of Railway Bridge and Culvert $(\mathrm{S})$, Chinese code.

The four codes will be used to do the design of bridge foundation, and the similarities, differences, advantages and disadvantages of each code will be investigated. Also the design will be checked by the numerical analysis and the suitability of using the structure according to the design would be found by making a comparison between

Table 1. Properties of the soil layers according to the geological column.

| Soil <br> description | Sampling <br> depth $(\mathbf{m})$ | Density <br> $\left(\mathbf{g} / \mathbf{c m}^{\mathbf{3}}\right)$ | Void ratio | Compressibility <br> $\left(\mathbf{C}_{\mathbf{c}}\right)$ | Internal friction <br> angle $\left.\left(\boldsymbol{\varphi} \mathbf{(}^{\circ}\right)\right)$ | Cohesion (c) <br> $\mathbf{k N / \mathbf { m } ^ { 2 }}$ | Compression <br> $\mathbf{m o d u l u s , ~} \mathbf{E}_{\mathbf{s}}$ <br> $(\mathbf{M P a})$ |
| :--- | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| Field soil | 1.90 | 1.86 | 0.93 | 0.52 | 14.2 | 20 | 12.00 |
| Silty clay | 3.90 | 1.93 | 0.76 | 0.21 | 6.4 | 36 | 15.00 |
| Silt | 5.90 | 1.91 | 0.88 | 0.21 | 17.4 | 10 | 20.20 |
| Silty clay | 21.90 | 1.98 | 0.77 | 0.43 | 20.4 | 13 | 15.73 |
| Silty clay | 23.45 | 1.98 | 0.77 | 0.43 | 20.4 | 13 | 15.73 |
| Silty clay | 29.70 | 1.91 | 0.95 | 0.33 | 6.4 | 36 | 15.87 |
| Silty clay | 31.30 | 2.06 | 0.64 | 0.33 | 6.4 | 36 | 15.87 |
| Silty clay | 33.30 | 2.00 | 0.67 | 0.33 | 6.4 | 36 | 15.9 |
| Silt | 36.05 | 2.00 | 0.67 | 0.33 | 15 | 26 | 21.73 |
| Silt | 39.30 | 1.94 | 0.93 | 0.31 | 11.3 | 28 | 22.85 |
| Silty clay | 43.80 | 2.11 | 0.54 | 0.17 | 20 | 19 | 16.84 |
| Silt | 47.80 | 2.02 | 0.70 | 0.28 | 11.6 | 39 | 24.92 |
| Silty clay | 51.80 | 2.02 | 0.84 | 0.22 | 18.6 | 51 | 17.13 |
| Clay | 57.80 | 2.03 | 0.70 | 0.11 | 5 | 54 | 8.10 |
| Clay | 60.80 | 1.90 | 0.78 | 0.24 | 5 | 54 | 9.0 |
| Silt | 62.70 | 2.00 | 0.62 | 0.30 | 15 | 26 | 26.12 |
| Silty clay | 63.3 | 2.02 | 0.84 | 0.22 | 18.6 | 51 | 18.10 |
| Silt | 67.5 | 2.00 | 0.62 | 0.30 | 15 | 26 | 28.3 |



Figure 1. Girder beam according to AASHTO code.
the Chinese code and the numerical analysis to avoid the problems of dangerous settlement and another with three codes to discuss the bearing capacity of single pile. The pile foundation design is a very important part of the bridge and the rest of the structures that the cost of this part is relatively high compared to other parts. Therefore, the choice of the correct and appropriate code will save a high value of the cost of construction, in addition to be the successful design of this part will mean success for the rest of the parts that are based on it.

## FIELD DATA

The data available from the soil profile, geological investigation report and soil properties are shown in Table 1.

The data in Table 1 were used for the design of bridge foundation, analysis of the bearing capacity and settle-ments. In addition, to analyze with the numerical program of finite element, and to calculate the settlement, strain, stress and active pore water pressure of the soil.

## RESULTS AND DISCUSSION

## Designs with codes

The manual design for the bridge foundation was done according to the data and the information available from the project site. The parameters used to design the bridge foundation of high speed rail way are as follows:

1. Taking a reinforced concrete beam as an example: The length of the beam is 32 m , the weight is 7862.88 kN . Figure 1 shows the standard beam according to AASHTO code.
2. Superimposed dead load (the dead loads above the beam) is 3792 kN .
3. Concrete pier column is 2 m in diameter, and lateral width is 4 m . The drop panel diameter is 4 m in both sides with top hat thickness of 20 cm . The total height of pier with the drop panel is 7.2 m . All dimensions and detailed information are shown in Figure 2. Therefore the total dead load applied from the structure on the foundation is 13378 kN .
4. Lateral swaying force of train, seismic force and the other horizontal loads are taken into consideration.
5. Live load from the superstructure is shown in Table 2 according to the standard of each code and the type of


Figure 2. The graph showing the dimensions of the sections and the details of structural elements of the design (all the dimensions in meter).

Table 2. Comparison of live loadings of different countries.

| Name of code | Live load (kN/m) |
| :--- | :---: |
| AASHTO code | 84.158 |
| BS code | 83.6 |
| Chinese code (CNS, 2002) | 71.175 |
| Chinese code (TB 10002.5-2005) | 77 |

train used in each country in addition to the other live loads as shown in Table 2.The values of live loads in Table 2 have been taken from multiple sources, by taking into consideration the higher loads and specifications referred to in the various codes. Unless protected as specified in Article 3.6.S.I (AASHTO code), abutments and piers located within a distance of 9000 mm to the edge of roadway, or within a distance of 15000 mm to the centerline of a railway track, shall be designed for an equivalent static force of 1800000 N , which is assumed to
act in any direction in a horizontal plane, at a distance of 1200 mm above ground. Figures 3 to 5 show the value of the loads imposed by the various trains and taken from different countries, where we note that the type and design of the train varies from state to state depending on the nature and purpose of use and transported material, etc by taking the same dimensions of the foundation and design but using four different codes. It can be shown in Table 3 that the design with the four codes is different in some parts of the bridge and similar in the other, that the number of steel bars in the Chinese codes is more than that of AASHTO code and BS code. For the four codes, pile cap dimension is $5 \times 6 \mathrm{~m}$, thickness, 1.5 m and 4 bored piles with diameter, 1 m and depth of pile, 62.7 m .

As shown in the Table 3, the number of reinforcing bars in the Chinese codes is larger than the AASHTO and the British codes 8110-1(1997).Therefore, the Chinese codes take into account the high safety factor when calculating the amount of reinforcement required, but at the same time,


Figure 3. The live load for steam locomotive and RA1 train used in Britain.

180 KN 180 KN 180 KN 180 KN


Figure 4. The live load for a train used in China.


Figure 5. The live loads of a train used in USA.
this design can be deemed economically because it provides the same dimensions of the foundation. Figures 6 and 7 show values of the reinforcement area of bending and shear for pile cap and piles respectively, it can be seen that the reinforcement area of TB 10002.5-2005 code is higher than the other codes. Appendix 1 shows the full details pile foundation reinforcements.

## Settlement estimation using Chinese code

The settlement of the pile foundation can be calculated from the following formula (Chinese Code, CNS

2002- R.0.4-8):

$$
\begin{equation*}
S=\psi_{p} \frac{Q}{l^{2}} \sum_{j=1}^{m} \sum_{i=1}^{n_{j}} \frac{\Delta h_{j, i}}{E_{s j, i}} \sum_{k=1}^{n}\left[\alpha I_{p, k}+(1-\alpha) I_{s 2, k}\right] \tag{1}
\end{equation*}
$$

where $S$ is the final calculated amount of settlement for pile foundation (mm). $\psi_{p}$ is the coefficient of experience of calculation of settlement of pile foundation, in the different districts, it shall be determined on the basis of the local measured data through statistical contrast; $Q$ is the additional load of single pile under the quasi

Table 3. Comparison of bridge design by using four codes.

| Name of code | Pile cap design | Pile design |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| AASHTO code | 25 bars \#9 (2.8 cm ) in the bottom mats for each direction | 21 bars \#9 (2.8 cm ) in the top mats for each direction | \#5 at 12 cm in the long and short direction for shear design | 16 bars \#8 (2.5 cm ) in the bottom of the pile | 24 bars \#8 $(2.5 \mathrm{~cm})$ in the middle of the pile | \#4 at 12 cm in the transverse direction for shear design |
| BS Code | 28 bars \#9 (2.8 $m$ ) in the bottom mats for each direction | 28 bars \#9 (2.8 cm ) in the top mats for each direction | \#5 at 11 cm in the long and short direction for shear design | 16 bars \#8 (2.5 cm ) in the bottom of the pile | 24 bars \#8 $(2.5 \mathrm{~cm})$ in the middle of the pile | \#4 at 12 cm in the transverse direction for shear design |
| $\begin{aligned} & \text { The (CNS, } \\ & \text { 2002) code } \end{aligned}$ | 29 bars (2.8 cm ) in each direction in the bottom mats | 22 bars (2.8 cm ) in each direction in the top mats | 1.6 cm at 10 cm in the long and short direction for shear design | 18 bars (2.5 cm ) in the bottom of the pile | 27 bars (2.5 cm ) in the middle of the pile | 1.2 cm at 10 cm in transverse direction for shear design |
| $\begin{array}{lr}\text { TB } & \text { 10002.5- } \\ \text { 2005, } & \text { Chinese }\end{array}$ code. | 47 bars (2.8 cm ) in each direction in the bottom mats | 22 bars (2.8 cm ) in each direction in the top mats | 1.6 cm at 10 cm in the long and short direction for shear design | 19 bars (2.5 cm ) in the bottom of the pile | 29 bars (2.8 cm ) in the middle of the pile | 1.2 cm at 10 cm in transverse direction for shear design |


| $\overline{\text { a }}$ |  |  |  |  |
| :---: | :---: | :---: | :---: | :---: |
| E ${ }^{350}$ |  |  |  |  |
| - 300 |  |  |  |  |
|  |  |  |  |  |
|  |  |  |  |  |
| 䓓 150 |  |  |  |  |
| ${ }_{\text {a }} 100$ |  |  |  |  |
| E 50 |  |  |  |  |
|  | pile cap at bottom | pile cap at top | pileat Min. moment | pileat Max. moment |
| ■AASHTO code | 160.32 | 134.67 | 81 | 121.6 |
| - BS Code | 179.56 | 179.56 | 81 | 121.6 |
| ■CNS, 2002 | 186 | 141 | 91.2 | 136.81 |
| ■TB 10002.5-2005 | 301.4 | 141 | 96.62 | 147 |

Figure 6. Bending reinforcement chart for different codes.
permanent combination of the vertical load effects; is the length of the pile; $m$ is the total amount of soil stratum within the range of compressive stratum under the plane of pile end; $n_{j}$ is the stratification number of the $i^{\text {th }}$ stratum soil under the plane of pile end; $\alpha$ is $\varphi / 4 ; \varphi$ is the angle of internal friction, and $I_{p, k}, l_{s 2, k}$ are the coefficients of stress influence.

The results can be obtained through the application of the aforementioned settlement Equation (1), after making the required calculations depending on the data available of the soil and the available information from design through the use of Excel program in order to simplify the solution as shown in the appendix 2, and therefore the
results have been included in Table 4.
As shown from Table 4 and Figure 8 that the maximum value for the settlement is about 22.683 mm at pressure of 1000 kPa . This value is within the permissible limit for the settlement. In TB10002.5-2005 code (3.2.1), the allowable settlement due to the dead load of bridge is between 40 and 80 mm , and for the high way BeijingShanghai Bridge is between 15 and 30 mm . While in "a total of $200 \mathrm{~km} / \mathrm{h}$ passenger railway interim design provisions" code, the allowable settlement is 50 mm .

For Ballast railway, there are two requirements:

## 1. The allowable settlement of the single foundation is



Figure 7. Shear reinforcement chart for different codes.

Table 4. The values of the pressure, load and settlement (Chinese Code).

| $\mathbf{P}(\mathbf{k P a})$ | load $\mathbf{( k N})$ | Settlement (mm) |
| :---: | :---: | :---: |
| 0 | 0 | 0 |
| 100 | 3000 | 1.034 |
| 200 | 6000 | 1.854 |
| 300 | 9000 | 2.843 |
| 400 | 12000 | 5.246 |
| 600 | 18000 | 10.492 |
| 800 | 24000 | 18.146 |
| 1000 | 30000 | 22.683 |

## load kN



Figure 8. Load settlement curve calculated by Equation 1.

80 mm .
2. The allowable settlement of two adjacent foundations is 40 mm .

Table 5 shows also the values of allowable settlements for ballasted track railway.

## Vertical ultimate bearing capacity of single pile

In order to determine the vertical ultimate bearing capacity of the single pile, a large uniform pressure was applied to the top of the pile. In the calculation, a pressure of 1000 kPa was imposed, which is equivalent to a resultant force of $30000 \mathrm{kN}(5 \times 6 \times 1000)$. The calculation gives the load versus settlement curve for the mid-point on the long side of the upper pile cap, as shown in Figure 9.

Figure 8 shows there is an obvious turning point on the load-settlement curve. Before that turning point, the loadsettlement curve is approximately linear. After the turning point, the settlement increases slightly as the load increases.

The Chinese Standard specifies key points for a single pile load test (CNS, 2002), which includes taking the load corresponding to the beginning of the steep drop on the measured load-settlement curve as the single pile bearing capacity. From Figure 8 , it can obtain the pressure corresponding to the steep drop point to be about 300 kPa , which is converted to a resultant force of about 9000 kN , that is, this value of the ultimate vertical bearing capacity of the single pile is smaller than the total vertical loads. The ultimate load-bearing capacity of the

Table 5. Ordinary ballasted track railway standards settlement (in Chinese).

| Technical standards for railway or railway grade | Settlement after <br> the general <br> location/cm | Transition section <br> settlement/cm | Settlement <br> rate (cm-a-1) |
| :--- | :--- | :---: | :---: | :---: |
| "Railway embankment design" (TB 1001- Class I-railway <br> 2005) Class II-railway | 20 | 10 | 5 |
| "A total of $200 \mathrm{~km} / \mathrm{h}$ passenger railway design Interim Provisions" | 15 | - | - |



Figure 9. The layout of the finite element model. (a) Load-cap-pile foundation; (b) Mesh.
single pile can be calculated in the clayey soils from the following formula (AASHTO code, 10.7.3.3.2a, $\alpha$ method):

$$
\begin{equation*}
F_{R D}=\left(\frac{1}{\gamma_{R D}}\right) \cdot \sum_{i=1}^{n} \alpha_{i} \cdot c_{u} \cdot A_{s} \tag{2}
\end{equation*}
$$

where, $F_{R D}$ is the load carried by cohesion between the soil and the pile shaft; $\alpha_{i}$ is the adhesion factor for earth layer; $c_{u}$ is the undrained shear strength of the soil; $A_{s}$ is the area of pile shaft in contact with the soil, and $\gamma_{R D}$ is a factor which should be $\geq 1.5$ for piles in friction material.

The adhesion factor $\alpha$ is taken as 0 for the first three meters where it is expected as a hole and fills material or week strata. For piles with constant cross sectional area,
the value of $\alpha$ can be taken as 1.0 , and for piles with tapered cross-sectional growth the value of $\alpha$ can be taken as 1.2.
$\sum_{i=1}^{n} c_{u} . \Delta L=1778.55 \mathrm{kN} / \mathrm{m}$
$\sum_{i=1}^{n} c_{u} \cdot A_{s}=3.14 \times 1778.55=5584.647 \mathrm{kN}$
$F_{R D}=(1 / 1.5) \times 1.0 \times 5584.647=3723.098 \mathrm{kN}$
$R_{b}=N_{c} C_{b} A_{b}$
where $R_{b}$ is the load carried by the end bearing of pile $N_{c}$

Table 6. Allowable pile bearing capacity of soil.

| $h / d$ | $[\sigma]$ |
| :--- | :--- |
| $h / d \leq_{4}$ | $[\sigma]=\sigma_{0}+k_{2} \gamma_{2}(h-3)$ |
| $4<h / d \leq_{10}$ | $[\sigma]=\sigma_{0}+k_{2} \gamma_{2}(4 d-3)+k_{2}^{\prime} \gamma_{2}(h-4 d)$ |
| $h / d>10$ | $[\sigma]=\sigma_{0}+k_{2} \gamma_{2}(4 d-3)+k_{2}^{\prime} \gamma_{2}(6 d)$ |

$h$ is the pile embedded depth (m); $d$ is the diameter of pile (m); by the "railway bridge foundation" and basis of design $\mathrm{k}_{2}$ is to take $1.0 ; \gamma_{2}$ is the average unit weight over the basement of severe soil.
is Terzaghi's bearing capacity factor, and $A_{b}$ is the cross sectional area of the pile.

For $\varphi=18.6^{\circ}, \mathrm{N}_{\mathrm{c}}=15.5$ (Braja, 2006).
$\mathrm{C}_{\mathrm{b}}=51 \mathrm{kN} / \mathrm{m}^{2}$
$\mathrm{A}_{\mathrm{b}}=\pi / 4\left(1^{2}\right)=0.785 \mathrm{~m}^{2}$
$R_{b}=15.5 \times 51 \times 0.785$
$=620.542 \mathrm{kN}$
$R=3723.098+620.542$
$=4343.640 \mathrm{kN}$
Therefore the value of the ultimate load-bearing capacity of the single pile is only $27 \%$ of the applied load including the live load, therefore the foundation need at least for four pile in order to be appropriate design. For the Chinese code, the following formula can be used for a single pile (CNS, 2002).
$R_{a}=q_{p a} A_{p}+u_{p} \Sigma q_{\text {sia }} l_{i}$
where $\mathrm{R}_{\mathrm{a}}$, the characteristic value of vertical-load bearing capacity of single pile; $\mathrm{q}_{\mathrm{pa}}$, $\mathrm{q}_{\text {sia }}$, the characteristic values of the end resisting force for end of pile, the side resisting force for pile are calculated from the statistical analysis of static loading test results in locality;
$A_{p}$, the cross sectional area for bottom end of pile; $u_{p}$, the peripheral length of pile shaft, and $\mathrm{l}_{\mathrm{i}}$, the thickness of the ith stratum of soil.
For different soil layers from the data and use the Excel program for calculation.

$$
\begin{aligned}
\Sigma \mathrm{q}_{\text {sia }} \mathrm{a}_{\mathrm{i}} & =5828.311 \mathrm{kN} \\
\mathrm{q}_{\mathrm{pa}} \mathrm{~A}_{\mathrm{p}} & =1013.43 \times(\pi / 4) \times 1^{2} \\
& =795.94 \mathrm{kN}
\end{aligned}
$$

$$
\begin{aligned}
R_{a} & =5828.311+795.94 \\
& =6624.251 \mathrm{kN}
\end{aligned}
$$

The aforementioned value is only $42.3 \%$ of the applied load including the live load. Therefore the assumed number of the piles is suitable for carrying the applied loads. This value is larger than that calculated from AASHTO code.

The bearing capacity for a single pile can be also calculated according to TB 10002.5-2005 code by the following formula:
$[P]=0.5 U \Sigma f_{i} l_{i}+m_{0} A[\sigma]$
where, $f_{i}$ is the ultimate of the soil pile frictional resistance; $m_{0}$ is reduction factor of pile resistance; $l_{i}$ is the length of the pile through the soil layer $\mathrm{i}(\mathrm{m})$; A is Pile heap area; U is the Pile cross-section perimeter ( m ) and $[\sigma]$ is allowable pile bearing capacity of soil ( kPa ), calculated according to Table 6; depth correction factor $k_{2}$ is 2.5 according to the code. Where $h$ is the pile embedded depth ( m ); $d$ is the diameter of pile ( m ); by the "railway bridge foundation" and basis of design $k_{2}^{\prime}$ is to take 1.0; $\gamma_{2}$ is the average unit weight over the basement of severe soil. In the design, the water table is at 2.35 m from the ground, therefore, the bulk density $\gamma_{2}$ is taken at 2.35 m from floating.

By the "practical foundations" knowledge $m_{0}=1.0$; computing the area by:
$\mathrm{A}=\pi \mathrm{d}^{2} / 4=\pi(1)^{2} / 4=0.79 \mathrm{~m}^{2}$
Pile circumference is
$\mathrm{U}=\pi \mathrm{d}=\pi \times 1.0=3.14 \mathrm{~m} ; \sigma_{0}=579 \mathrm{kPa} ; k_{2}=2.5 ; k_{2}^{\prime}=1.0 ;$
$\gamma_{2}=19.3 \mathrm{kN} / \mathrm{m}^{3} . \Sigma f_{i} l_{i}=3712.3 \mathrm{kN} / \mathrm{m}$,
the frictional resistance along the pile depth.
$[\sigma]=579+2.5 \times 20.2 \times(4 \times 1.0-3)+1.0 \times 19.3 \times 6 \times$ $1.0=745.3 \mathrm{kPa}$

The allowable bearing capacity of single pile [P]:
$[P]=0.5 \times 3.14 \times 3712.3+1.0 \times 0.79 \times 745.3=$ 6417.098 kN

The value of bearing capacity calculated in the foregoing is only $40.5 \%$ of the applied load and approves the number of piles choosing in the design.
The results of the settlements and bearing capacity are summarized in Table 7:
It is noted from Table 7 that the value of final settlement in Chinese code (CNS, 2002) has a reasonable values

Table 7. The results of the settlements and bearing capacity.

| Final settlement at pressure of $\mathbf{1 0 0 0} \mathbf{~ k P a}$ | 22.683 mm, Chinese code (CNS, 2002) |  |  |
| :--- | :---: | :---: | :---: |
| Bearing capacity for single pile | 4343.640 kN | 6624.251 kN Chinese | 6417.098 kN Chinese code |
|  | (AASHTO code) | code (CNS, 2002) | (TB 10002.5-2005) |

Table 8. Material parameters for pile foundation.

| Item | Unit weight $\left(\mathbf{k N} / \mathbf{m}^{\mathbf{3}}\right)$ | Poisson ratio | Shear modulus (GPa) |
| :--- | :---: | :---: | :---: |
| Pile cap | 24 | 0.15 | 28 |
| Pile | 26 | 0.10 | 30 |

and is a good sign for this code as a faithful and takes into consideration the high values for the settlement and gives indicators of hazardous settlement in the future, but the bearing capacity of the soil in the (CNS, 2002) is higher than the U.S. code, which gives the incorrect impression when calculating the number of piles required and this number could be less than the actual requirement, therefore the last code use factor of safety equal to 1.2 to increase the number of piles. While for the Chinese code (TB 10002.5-2005), the value of bearing capacity is higher than that calculated with AASHTO code and lesser than that calculated with Chinese code (CNS, 2002), so it is more safer than the first Chinese code in the calculation of the number of piles required for the design and thus the structure will be more stable, in addition to this code, use factor of safety ranging between 1.3 and 1.8 to increase the number of piles.

## Analysis with Plaxis 3D program for finite element

Another analysis, but using the numerical analysis of the Plaxis program of finite elements to ascertain the values calculated previously manually and found out the design suitable to withstand the external loads, by calculating the value of vertical displacement and other parameters relying on the same dimensions calculated from the design and the same loads applied. The analysis of the program depends on the same soil investigations information and parameters of the soil strength, as shown in Table 1. The properties of the piles and pile cap material are shown in Table 8.
In the finite element analysis, the Mohr-Coulomb model with undrained conditions was used to simulate the constitutive relationship for the soil material and the linear elastic non-porous material model was used for the piles and pile cap of reinforced concrete structure. This model requires five basic input parameters, namely a Young's modulus, E, a Poisson's ratio,v, a cohesion, c, a friction angle, $\varphi$, and a dilatancy angle, $\Psi$. The implication of these requirements may be appreciated by considering the Mohr-Column equation in the following form (Terzaghi
et al., 1996):
$S u_{0}=C_{m}^{\prime}+(\sigma-u) \tan \varphi_{m}^{\prime}$
$S u_{0}$ is the undrained shear strength. The parameters $C^{\prime}{ }_{m}$ and $\varphi_{m}^{\prime}$ are, respectively, the cohesion intercept and friction angle mobilized at yield, $\sigma$ is the applied normal stress and the pore water pressure $u$ is the sum of hydrostatics or steady-seepage pore water pressure $u_{0}$ and the shearing pore water pressure $\Delta u$.
The load applied in the model is the same as that used for the previous design and analysis which is about 445 kPa according to the AASHTO code. The results of the numerical analysis are shown in Figures 10 to 13. The displacement value can be shown in Figure 10 that the maximum value for displacement equal to -20.95 mm , the minus sign refers the direction of the displacement to down, when compared, this value with maximum value maintained from the manual calculations shown in Figure 8 is relatively small value that in the considerations of the numerical analysis is considered accepted. Other values are maintained from the numerical calculations like total Cartesian strain, Cartesian total stress and active pore water pressure in the Figures 11 to 13, respectively; all these calculations are reasonable. Figure 13 shows the indication for active stress of the soil; therefore, this value of the pore pressure is relatively small and it will not increase the final value of the consolidation settlement during the time of the consolidation due to the loading effects coming from the structure.

## ADVANTAGE AND DISADVANTAGE OF CODES

Any code used in the design, whether the structure is a bridge or other, has the advantages and disadvantages, but the country remains a user of this code reticent on the defects of the fact that this code fits the nature of use and privacy to that country, therefore the researchers and designers are doing their best to develop the code on their country and to overcome the difficulties of use, in addition to devise new ways to fit the future conditions.

Plaxis Output Version 2.2.0.327

Figure 10. The distribution of the shading total vertical displacements (Uy) for all the layers of the model.

## AASHTO code

## Advantage

1. It is one of the more economically codes in calculation of the amount of reinforcement for all parts of structure and at the same time take into account the safety and durability.
2. Shear design is very convenient and gives the equations for multi-calculation of the amount of reinforcement required to resist the stresses generated by the shear loads and thus ensure an appropriate design in this aspect.
3. Design equations in this code do not possess complexity, the design methods are seamless and smooth in addition to the presence of templates and standard design procedures for all parts of the structure. 4. It is one of the more commonly used codes among the engineers all over the world, which means it is scientifically acceptable and rolling heavily.

## Disadvantage

There is need for some modifications, that is why United States itself State transportation departments regularly

Plasis OAptV Version 220.327


Figure 11. The distribution of the shading total Cartesian strains for all the layers of the model.
issue amendments to the AASHTO code. These amendments can offer additional requirements to certain design criteria or even outright exceptions (Wan et al., 2005).

## BS code

## Advantage

1. Most developing countries especially that which does
not possess a special code based on this code because it is close to the conditions of most countries and that fits their requirements, in addition to the economic side available in this code compared with others.
2. Easy to use through the existence of charts ready and directly to calculate the amount of reinforcement area are for all structural sections depending on the values of the ultimate moments and dimensions of the section.
3. Provides all the necessary requirements for resistance to severe weather conditions, for example, heavy

Pais OtqutVursion 220.327


Figure 12. The distribution of the Cartesian total stress for all the layers of the model.

Plaxis Output Version 2.2.0.327


Figure 13. The distribution of the active pore pressure for all the layers of the model.
snowfall in the United Kingdom.

## Disadvantage

It did not have allocation or rules in earthquake design consideration for bridge structure. So it is not suitable for design in countries exposed to the effects of earthquakes.

## (CNS, 2002) code

## Advantage

1. Safety factor in calculating the amount of reinforcement required is relatively high compared to the rest of the codes used in this study, and thus can use this code in order to get high requirements in the design.
2. The value of settlement calculated to be relatively high due to the fact that the equation used with high precision and has many determinants, and therefore this result of calculating the high settlement will give control of the settlement and the risk to help predict the occurrence of early failure.

## Disadvantage

1. Account shear equations provided in this code are not given enough indexes to calculate the stresses generated as a result of shear loads, and hence the rest of codes take into account this aspect carefully and provide adequate safety factor for this purpose. Thus, in this code minimum design appropriate were taken to calculate the shear.
2. Higher safety factor in the calculation of reinforcement steel is possibly non-economic in design.
3. The bearing capability of the soil is high compared to the rest of the codes, which leads to reduction in the number of the calculated piles and thus adversely affect the structure safety.

## (TB 10002.5-2005) code

## Advantage

1. The reinforcing steel calculation is the highest compared to other codes which gives greater protection of the structure.
2. The bearing capacity of single pile is low as compared to the CNS, 2002 code which lead to increase in the number of piles at the design and thereby increase the safety of structure.

## Disadvantage

Its disadvantage is the absence of adequate equations to
verify the shear strength of the structure. This situation is similar to the Chinese code aforementioned (CNS, 2002).

## Conclusions

Here we may draw the following conclusions.

1. The design of a bridge or any other structure with more than one code gives a difference in the design due to the nature of the country using this code. In this paper, it can be seen that there are more reinforcement area with design in the Chinese codes compared with the AASHTO code and BS code, therefore it can be concluded that the first two are not the economists in the design.
2. The settlement calculated satisfies the requirement of normal operation of a high-speed rail way. The settlement calculated in Chinese code (CNS, 2002) is suitable to give indication of the severe conditions of the settlement.
3 . The bearing capacity of the single pile calculated by the AASHTO code is only $65.57 \%$ of that calculated by the Chinese code (CNS, 2002) and $67.75 \%$ of that calculated by TB (10002.5-2005) code which provide high safety to provide the suitable number of piles by the first code.
3. The analysis with 3D Plaxis program gives accepted results compared with that calculated by using the settlement equations of Chinese (CNS, 2002) code. This provides more check for the design of the bridge and gives more agreement and suitability for the design.
4. The shear design in the AASHTO and BS codes is more conservative than the two Chinese codes.

## RECOMMENDATIONS FOR FUTURE RESEARCH

For future researches, the superstructure can be designed with the four codes to show the comparison and the suitability of using the better one for the design. Also other similar codes used in China can be studied for design and find which is the better and suitable for the severe conditions of design.

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## Appendix



Appendix 1. The detail section of reinforcement according to AASHTO code.

Appendix 2. The calculation by excel program for the equation 3 (Chinese code).

| Depth |  | n | m | A |  | B | F |  | A |
| :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: | :---: |
| 1.9 |  | 0.031898 | 0.030303 | 0.970 |  | 1.030797 | 0.0439 |  | 0.970221 |
| 3.9 |  | 0.031898 | 0.062201 | 0.938 |  | 1.06268 | 0.0699 |  | 0.938341 |
| 5.9 |  | 0.031898 | 0.094099 | 0.906 |  | 1.094564 | 0.0993 |  | 0.906463 |
| 7.9 |  | 0.031898 | 0.125997 | 0.874 |  | 1.126449 | 0.1299 |  | 0.874585 |
| 9.9 |  | 0.031898 | 0.157895 | 0.842 |  | 1.158334 | 0.1610 |  | 0.842709 |
| 11.9 |  | 0.031898 | 0.189793 | 0.810 |  | 1.19022 | 0.1924 |  | 0.810835 |
| 13.9 |  | 0.031898 | 0.221691 | 0.778 |  | 1.222107 | 0.22397 |  | 0.778963 |
| 15.9 |  | 0.031898 | 0.253589 | 0.747 | 093 | 1.253994 | 0.2555 |  | 0.747093 |
| 17.9 |  | 0.031898 | 0.285486 | 0.715 |  | 1.285882 | 0.2872 |  | 0.715225 |
| 19.9 |  | 0.031898 | 0.317384 | 0.683 |  | 1.31777 | 0.3189 |  | 0.683361 |
| 21.9 |  | 0.031898 | 0.349282 | 0.651 |  | 1.349659 | 0.3507 |  | 0.651499 |
| 23.45 |  | 0.031898 | 0.374003 | 0.626 |  | 1.374373 | 0.3753 |  | 0.626809 |
| 24.7 |  | 0.031898 | 0.393939 | 0.606 |  | 1.394304 | 0.395 |  | 0.606899 |
| 26.7 |  | 0.031898 | 0.425837 | 0.575 |  | 1.426194 | 0.427 |  | 0.575048 |
| 27.8 |  | 0.031898 | 0.443381 | 0.557 |  | 1.443734 | 0.4445 |  | 0.557532 |
| 29.7 |  | 0.031898 | 0.473684 | 0.527 |  | 1.474029 | 0.4747 |  | 0.527282 |
| 31.3 |  | 0.031898 | 0.499203 | 0.501 |  | 1.499542 | 0.5002 |  | 0.501812 |
| 33.3 |  | 0.031898 | 0.5311 | 0.469 |  | 1.531433 | 0.5320 |  | 0.469983 |
| 34.05 |  | 0.031898 | 0.543062 | 0.458 |  | 1.543392 | 0.5439 |  | 0.45805 |
| 36.05 |  | 0.031898 | 0.57496 | 0.426 |  | 1.575283 | 0.5758 |  | 0.426235 |
| 37.4 |  | 0.031898 | 0.596491 | 0.404 | 768 | 1.59681 | 0.5973 |  | 0.404768 |
| 39.3 |  | 0.031898 | 0.626794 | 0.374 |  | 1.627107 | 0.6276 |  | 0.374566 |
| 40.3 |  | 0.031898 | 0.642743 | 0.358 |  | 1.643053 | 0.6435 |  | 0.358678 |
| 42.3 |  | 0.031898 | 0.674641 | 0.326 |  | 1.674945 | 0.6753 |  | 0.326919 |
| 43.8 |  | 0.031898 | 0.698565 | 0.303 |  | 1.698864 | 0.6992 |  | 0.303118 |
| 45.8 |  | 0.031898 | 0.730463 | 0.271 |  | 1.730756 | 0.731 |  | 0.271418 |
| 47.8 |  | 0.031898 | 0.76236 | 0.239 |  | 1.762649 | 0.7630 |  | 0.239771 |
| 49.8 |  | 0.031898 | 0.794258 | 0.20 |  | 1.794542 | 0.7948 |  | 0.2082 |
| 51.8 |  | 0.031898 | 0.826156 | 0.176 |  | 1.826435 | 0.8267 |  | 0.176746 |
| 53.8 |  | 0.031898 | 0.858054 | 0.145 | 486 | 1.858328 | 0.8586 |  | 0.145486 |
| 55.8 |  | 0.031898 | 0.889952 | 0.114 | 578 | 1.890221 | 0.8905 |  | 0.114578 |
| 57.8 |  | 0.031898 | 0.92185 | 0.084 |  | 1.922115 | 0.922 |  | 0.084409 |
| 60.8 |  | 0.031898 | 0.969697 | 0.043 |  | 1.969955 | 0.970 |  | 0.043997 |
| 62.7 |  | 0.031898 | 1 | 0.031 | 898 | 2.000254 | 1.0005 |  | 0.031898 |
| 80 |  | 0.031898 | 1 | 0.031 |  | 2.000254 | 1.0005 |  | 0.031898 |
| Ip | Is2 | S | s100 | s200 | s300 | s400 | s600 | s800 | s1000 |
| -0.00247 | -0.11396 | - $2.8 \mathrm{E}-05$ | -5.5E-06 | -1.1E-05 | -1.7E-05 | -2.2E-05 | -3.3E-05 | -4.4E05 | -5.5E-05 |
| -0.00986 | -0.38432 | $2-4.1 \mathrm{E}-05$ | -8.2E-06 | -1.6E-05 | -2.4E-05 | -3.3E-05 | -4.9E-05 | -6.5E-05 | -8.2E-05 |
| -0.02154 | -0.61267 | 7 -6.6E-05 | -1.3E-05 | -2.6E-05 | -4E-05 | -5.3E-05 | -7.9E-05 | -0.00011 | -0.00013 |
| -0.03706 | -0.78725 | -0.00011 | -2.1E-05 | -4.2E-05 | -6.3E-05 | -8.4E-05 | -0.00013 | -0.00017 | -0.00021 |
| -0.05618 | -0.92185 | $5-0.00012$ | -2.4E-05 | -4.8E-05 | -7.2E-05 | -9.6E-05 | -0.00014 | -0.00019 | -0.00024 |
| -0.0788 | -1.02709 | -0.00014 | -2.7E-05 | -5.4E-05 | -8.1E-05 | -0.00011 | -0.00016 | -0.00022 | -0.00027 |
| -0.10499 | -1.10991 | $1-0.0002$ | -4.1E-05 | -8.1E-05 | -0.00012 | -0.00016 | -0.00024 | -0.00033 | -0.00041 |
| -0.13495 | -1.17487 | -0.00022 | -4.3E-05 | -8.6E-05 | -0.00013 | -0.00017 | -0.00026 | -0.00035 | -0.00043 |
| -0.16905 | -1.22501 | $1-0.00023$ | -4.5E-05 | -9E-05 | -0.00014 | -0.00018 | -0.00027 | -0.00036 | -0.00045 |
| -0.20781 | -1.26242 | -0.00027 | -5.4E-05 | -0.00011 | -0.00016 | -0.00022 | -0.00033 | -0.00043 | -0.00054 |
| -0.25197 | -1.2885 | -0.00027 | -5.4E-05 | -0.00011 | -0.00016 | -0.00022 | -0.00032 | -0.00043 | -0.00054 |
| -0.29053 | -1.30149 | -0.00021 | -4.2E-05 | -8.5E-05 | -0.00013 | -0.00017 | -0.00025 | -0.00034 | -0.00042 |
| -0.32481 | -1.30759 | -0.00012 | -2.4E-05 | -4.8E-05 | -7.3E-05 | -9.7E-05 | -0.00015 | -0.00019 | -0.00024 |

Appendix 2. Contd.

| -0.38658 | -1.30941 | -0.0002 | $-4 \mathrm{E}-05$ | $-7.9 \mathrm{E}-05$ | -0.00012 | -0.00016 | -0.00024 | -0.00032 | -0.0004 |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :---: |
| -0.42476 | -1.30626 | -0.00011 | $-2.2 \mathrm{E}-05$ | $-4.3 \mathrm{E}-05$ | $-6.5 \mathrm{E}-05$ | $-8.6 \mathrm{E}-05$ | -0.00013 | -0.00017 | -0.00022 |
| -0.49918 | -1.29378 | -0.0002 | $-4 \mathrm{E}-05$ | $-8 \mathrm{E}-05$ | -0.00012 | -0.00016 | -0.00024 | -0.00032 | -0.0004 |
| -0.57178 | -1.27613 | -0.00017 | $-3.3 \mathrm{E}-05$ | $-6.6 \mathrm{E}-05$ | $-9.9 \mathrm{E}-05$ | -0.00013 | -0.0002 | -0.00027 | -0.00033 |
| -0.67852 | -1.24427 | -0.0002 | $-4.1 \mathrm{E}-05$ | $-8.1 \mathrm{E}-05$ | -0.00012 | -0.00016 | -0.00024 | -0.00032 | -0.00041 |
| -0.72405 | -1.22932 | $-7.5 \mathrm{E}-05$ | $-1.5 \mathrm{E}-05$ | $-3 \mathrm{E}-05$ | $-4.5 \mathrm{E}-05$ | $-6 \mathrm{E}-05$ | $-9 \mathrm{E}-05$ | -0.00012 | -0.00015 |
| -0.86369 | -1.18071 | -0.00019 | $-3.9 \mathrm{E}-05$ | $-7.8 \mathrm{E}-05$ | -0.00012 | -0.00016 | -0.00023 | -0.00031 | -0.00039 |
| -0.97618 | -1.13997 | -0.00012 | $-2.5 \mathrm{E}-05$ | $-5 \mathrm{E}-05$ | $-7.5 \mathrm{E}-05$ | $-1 \mathrm{E}-04$ | -0.00015 | -0.0002 | -0.00025 |
| -1.16692 | -1.07019 | -0.00017 | $-3.3 \mathrm{E}-05$ | $-6.7 \mathrm{E}-05$ | -0.0001 | -0.00013 | -0.0002 | -0.00027 | -0.00033 |
| -1.28639 | -1.02681 | $-6.5 \mathrm{E}-05$ | $-1.3 \mathrm{E}-05$ | $-2.6 \mathrm{E}-05$ | $-3.9 \mathrm{E}-05$ | $-5.2 \mathrm{E}-05$ | $-7.8 \mathrm{E}-05$ | -0.0001 | -0.00013 |
| -1.57752 | -0.92375 | $-9.8 \mathrm{E}-05$ | $-2 \mathrm{E}-05$ | $-3.9 \mathrm{E}-05$ | $-5.9 \mathrm{E}-05$ | $-7.8 \mathrm{E}-05$ | -0.00012 | -0.00016 | -0.0002 |
| -1.85604 | -0.82945 | $-7.1 \mathrm{E}-05$ | $-1.4 \mathrm{E}-05$ | $-2.9 \mathrm{E}-05$ | $-4.3 \mathrm{E}-05$ | $-5.7 \mathrm{E}-05$ | $-8.6 \mathrm{E}-05$ | -0.00011 | -0.00014 |
| -2.34246 | -0.67494 | -0.00013 | $-2.7 \mathrm{E}-05$ | $-5.4 \mathrm{E}-05$ | $-8.1 \mathrm{E}-05$ | -0.00011 | -0.00016 | -0.00022 | -0.00027 |
| -3.02485 | -0.47722 | -0.00011 | $-2.3 \mathrm{E}-05$ | $-4.5 \mathrm{E}-05$ | $-6.8 \mathrm{E}-05$ | $-9.1 \mathrm{E}-05$ | -0.00014 | -0.00018 | -0.00023 |
| -4.023 | -0.21907 | $-8.2 \mathrm{E}-05$ | $-1.6 \mathrm{E}-05$ | $-3.3 \mathrm{E}-05$ | $-4.9 \mathrm{E}-05$ | $-6.5 \mathrm{E}-05$ | $-9.8 \mathrm{E}-05$ | -0.00013 | -0.00016 |
| -5.56038 | 0.127999 | $-4.5 \mathrm{E}-05$ | $-8.9 \mathrm{E}-06$ | $-1.8 \mathrm{E}-05$ | $-2.7 \mathrm{E}-05$ | $-3.6 \mathrm{E}-05$ | $-5.4 \mathrm{E}-05$ | $-7.1 \mathrm{E}-05$ | $-8.9 \mathrm{E}-05$ |
| -8.08488 | 0.614089 | $-1.6 \mathrm{E}-05$ | $-3.2 \mathrm{E}-06$ | $-6.3 \mathrm{E}-06$ | $-9.5 \mathrm{E}-06$ | $-1.3 \mathrm{E}-05$ | $-1.9 \mathrm{E}-05$ | $-2.5 \mathrm{E}-05$ | $-3.2 \mathrm{E}-05$ |
| -12.5597 | 1.334182 | $1.09 \mathrm{E}-05$ | $2.18 \mathrm{E}-06$ | $4.36 \mathrm{E}-06$ | $6.53 \mathrm{E}-06$ | $8.71 \mathrm{E}-06$ | $1.31 \mathrm{E}-05$ | $1.74 \mathrm{E}-05$ | $2.18 \mathrm{E}-05$ |
| -21.0475 | 2.480547 | $2.37 \mathrm{E}-05$ | $4.75 \mathrm{E}-06$ | $9.49 \mathrm{E}-06$ | $1.42 \mathrm{E}-05$ | $1.9 \mathrm{E}-05$ | $2.85 \mathrm{E}-05$ | $3.8 \mathrm{E}-05$ | $4.75 \mathrm{E}-05$ |
| -36.1635 | 5.669654 | 0.000385 | $7.7 \mathrm{E}-05$ | 0.000154 | 0.000231 | 0.000308 | 0.000462 | 0.000616 | 0.00077 |
| 0.099287 | 7.035799 | 0.001122 | 0.000224 | 0.000449 | 0.000673 | 0.000898 | 0.001347 | 0.001796 | 0.002245 |
| 0.099287 | 7.035799 | 0.010219 | 0.002044 | 0.004088 | 0.006132 | 0.008175 | 0.012263 | 0.016351 | 0.020439 |

$n=r / l, m=z / l, A^{2}=n^{2}+(m-1)^{2}, B^{2}=n^{2}+(m+1)^{2}, F^{2}=n^{2}+m^{2}, r=$ horizontal distance between the calculating point and the axis of pile shaft, $z=$ vertical distance between the calculated stress point and the capping base surface and $I=$ length of the pile.


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