Assessment of Stress Loss Evaluation Capability of Design Software and IRC Codes in Post-Tensioning Members

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Abstract: Post tension members with curved cable profile are generally used for longer spans. The curved cable profile improves the shear resistance of the girders. Due to the material property, there will be losses in pressess applied initially. Commonly the prestress losses are categorized under two groups. Losses due to friction between cables and materials, due to elastic shortening of concrete, due to wobbling effect and due to anchorage slip are the immediate losses. Creep and shrinkage of concrete and relaxation of stress in steels are the time dependent losses. In Indian Practice the stress losses are calculated base on different codal provisions such as IS 1343-1980, IRC 18-2000 and IRC 112-2010. In this study the effectiveness of the stress loss calculated manually by IRC 112-2010 and design software is compared. In this thesis a prestress concrete bridge girder of 10m span with single curved cables profile is considered for the study. The stress losses are calculated with one and both end stressing. The total losses were calculated using the Bridge design software and IRC112-2011 with same coefficients and dimensions. When the results were compared the relaxation losses was is obtained same from both manual calculation and software. The relative humidity of materials is automatically assed by the software, but it failed to provide a critical stress loss variation. When the losses due to shrinkage and creep with normal calculation and that obtained from software about 10% variation is identified. This causes the major variations in stress loss calculation. For the immediate stress losses such as friction both methods showed the same values. Usually in manual calculation the elastic shortening loss is consider as zero for single cable. But when analysis in software it is providing a value for the loss in single cable. Due to the limitation of software implemented optimization algorithms, the software generate suboptimal design compared to manual design. When those results were compared, it is necessary to improve the efficiency of the Design software.

Keywords: Design software, Post-tension, Stress lose, Tendons

1. Introduction

Now a days there are many Bridge design and analysis software are available in the market. In olden times the designers use the manual methods for the design purpose. Now Because of time effectiveness designers prefer to use design software than the manuals. Therefore it is necessary to check the effectiveness of design software’s available in the market. Calculation of stress losses by means of design software are tedious process. In these days also stress losses are mainly calculated by manual methods even though there are many software are available in the market for stress loss calculation. In this study effectiveness of the stress loss by means of manual methods and software method on a pre stressed concrete bridge is checked. In prestressed concrete, estimation of losses plays vital role in arriving at the residual prestress.

2. Principles of Prestressing

The functions of prestressing are to place the concrete structure under compression in those regions where the load causes tensile stress. Tension caused by the load will first have to call off the compression induced by the prestressing before it may crack the concrete.

Since the tensile strength of the concrete is low, a homogeneous concrete beam has very little flexural strength. To offset these deficiencies, steel reinforcement are provided near the bottom of simple beams to carry tensile stresses. However, a substantial region of concrete below the neutral axis merely retains the reinforcement in that position, but this tensile strength is neglected in computation for the flexural strength in case of reinforced concrete beams. If the tensile reinforcement of the beam is subjected to tensile stresses before applying the external loads, then compressive stresses were induced in the concrete of the beam (and it is done by prestressing). Usually the tensile stresses in the concrete caused due to the external loads are totally absorbed or counteracted by compressive stresses in concrete, resulting from prestressing reinforcement. The concrete, therefore, is being used well in resisting tensile stresses formed by external loads rather than being ignored as in case of reinforced concrete.

Prestressed concrete can be applied to about all concrete constructions where ordinary reinforced concrete is commonly used. But due to high cost or prestressing and good quality material used, its use is made under unusual condition, particularly for the prestress members. In addition to structural precast members, viz., joists, beams, slabs, columns, girders, etc, prestressed concrete are used for the framed multi-storeyed buildings. A large variety of industrial structures such like silos, roof trusses, water tanks, piles, pipes, nuclear power stations, factories, steel plants, electric
3. Scope of Study

- To reduce the time involved in designing the structures.
- To find the dependability of Bridge Design software over the tedious manual designing.
- To evaluate the performance of Bridge design software.
- To develop a better design methodology combines the manual and the Bridge design software.

4. Objective of Study

- To study the IRC different code manual.
- Stress loss calculation of girder by using IRC 112-2010.
- Simulation of different tendon profile on girder by Bridge design software.
- To compare the effectiveness of Bridge design software with manual calculation.

5. Material specifications

For the comparison the grade of concrete is taken as M40 and the Partial factor on strength of concrete \( \gamma_c \) is taken as 1.5. The prestressing time after concreting is 28days as per IRC112:2010. The pre-stressing steel Type and dia. of strands 7ply-12.7mm-II of low relaxation type having the dia of 12.7mm, the other details are taken from IRC: 112:2011 and the breaking load of each strand \( F_{pu} \) is 183.71kN.

In Reinforcing steel the Characteristic strength of longitudinal steel \( f_y \) is 415 N/mm². Partial factor on strength of steel \( \gamma_s \) is 1.15 is taken from Cl.6.2.2 of IRC: 112:2011.

Prestressing force at center after friction and slip loss in cable 1 and 2 is 157t and the Prestressing force at center after friction and slip in cable 3 is taken as 131t.

The cross section of the deck and girder specifications are shown in the figure 1 and 2.

6. Loss Calculation

The Vertical and Horizontal profile of cables are shown in figure 2 and 3. It is having the profile eccentricity of 0.52m from the neutral axis.

<table>
<thead>
<tr>
<th>Cable</th>
<th>No of Strands</th>
<th>Dia of Strands (mm)</th>
<th>Area of Strands (mm²)</th>
<th>Jack end stress (N/mm²)</th>
<th>Jack end Force (kN)</th>
<th>Active</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>10</td>
<td>12.7</td>
<td>98.8</td>
<td>1406</td>
<td>1389</td>
<td>1</td>
</tr>
<tr>
<td>C2</td>
<td>1</td>
<td>12.7</td>
<td>98.8</td>
<td>1406</td>
<td>1389</td>
<td>1</td>
</tr>
<tr>
<td>C3</td>
<td>10</td>
<td>12.7</td>
<td>98.8</td>
<td>1406</td>
<td>1389</td>
<td>1</td>
</tr>
</tbody>
</table>

The calculation of post tensioning stress losses are manually calculated by IRC 112:2010.

a) Loss due to Friction and Wobbling Effect.

Coefficient of Friction \( k = 0.002 \)
Wobble coefficient \( \mu = 0.17 \)
Deviation angle of cable in Y-dir. b/w support & mid-span \( \theta_h = 0.045 \) rad
Deviation angle of cable in Z-dir. b/w support & mid-span \( \theta_v = 0.000 \) rad
Gross angle of deviation \( (\theta_h^2 + \theta_v^2) = 0.045 \) rad

Intial prestress at end= 1406 N/mm²

Stress at mid-span \( P_x = P_{e} e^{-\mu(\theta_h^2 + \theta_v^2)} = 1381 \) N/mm².

Loss of stress at mid-span =25 N/mm².

b) Loss due to Slip at Anchorages.

Anchorage slip S = 6 mm

Slope of stress profile \( \beta = P_{e} e^{-\mu(\theta_h^2 + \theta_v^2)} / (L/2) = 0.0028 \)

Slip length \( L_s = \sqrt{S \cdot \frac{E_s}{\beta}} = 20.46m \)

Stress at Jack end due to slip loss = 1406-2x20460x0.0028 = 1292 N/mm².

Stress at the end of slip length from jack = 1406-20460x0.0028 = 1349 N/mm².

Loss of stress at mid-span = 84 N/mm².
c) Losses due to Elastic Deformation of Concrete 
Increase in concrete stress at mid-span point of Cable-4: 
Due to stressing Cable-1= $P_1/A_{n0} + P_1\epsilon_{ypd} \epsilon_{ps}/I_n = 4.2 \text{ N/mm}^2$. 
Due to stressing Cable-2= $P_2/A_{n0} + P_2\epsilon_{ypd} \epsilon_{ps}/I_n = 4.2 \text{ N/mm}^2$. 
Due to stressing Cable-3= $P_3/A_{n0} + P_3\epsilon_{ypd} \epsilon_{ps}/I_n = 4.2 \text{ N/mm}^2$. 
Gross stress increase in concrete $f_{ck,a}=13\text{Mpa}$. 
Bending moment due to D.L. = 232KNm.
Fibres stress at the level of Cable-4 due to D.L. = 2.7\text{N/mm}^2. 
Net fibre stress at the level of Cable-4 due to D.L. = 12.4 N/mm2. 

f) Losses due to Creep of Concrete 
Age of concrete in years at the moment considered $t=100\text{years}$. 
Age of concrete at loading in days $t_0=15\text{days}$. 
Initial pre-tress at mid-span = 1406 N/mm2. 
Initial prestress at mid-span = 1240 N/mm2. 

| Table 2: Details of Shrinkage loss calculation |
|---|---|---|---|---|
| t/ day | At 1st stage prestressing | At full stress transfer | At construction | Long term |
| $t-t_0$/ day | 8 | 29 | 31 | $\infty$ |
| $\beta_1$ | 0.43 | 0.66 | 0.67 | 1.00 |
| $\beta_2$ | 0.00 | 0.02 | 0.02 | 0.98 |
| $\epsilon_{sa}$ | 10^-4 | | | |
| $c_{sa}$ | | 24 | 36 | 37 |
| $\epsilon_{sa}$ | 10^-4 | | | |
| $c_{sa}$ | | 00 | 4 | 180 |
| $\epsilon_{s}$ | 10^-4 | | | |
| $c_{s}$ | | 24 | 40 | 41 |
| $\epsilon_{s,E_p}$ | N/mm² | 5 | 8 | 8 |
| $\epsilon_{s,E_p}$ | N/mm² | | | 46 |

Table 3: Details of Creep losses 
<table>
<thead>
<tr>
<th>t/ day</th>
<th>At 1st stage prestressing</th>
<th>At full stress transfer</th>
<th>At construction</th>
<th>Long term</th>
</tr>
</thead>
<tbody>
<tr>
<td>$t-t_0$/ day</td>
<td>15</td>
<td>29</td>
<td>31</td>
<td>$\infty$</td>
</tr>
<tr>
<td>$\beta_1$</td>
<td>0.00</td>
<td>0.25</td>
<td>0.26</td>
<td>0.99</td>
</tr>
<tr>
<td>$\phi(t_0)$</td>
<td>0.00</td>
<td>0.46</td>
<td>0.48</td>
<td>1.85</td>
</tr>
</tbody>
</table>

Due to stressing Cable-1: $P_1/A_{n0} + P_1\epsilon_{ypd} \epsilon_{ps}/I_n = 1.6 + 2.6 = 4.2 \text{ N/mm}^2$. 
Due to stressing Cable-2: $P_2/A_{n0} + P_2\epsilon_{ypd} \epsilon_{ps}/I_n = 1.6 + 2.6 = 4.2 \text{ N/mm}^2$. 
Due to stressing Cable-3: $P_3/A_{n0} + P_3\epsilon_{ypd} \epsilon_{ps}/I_n = 1.6 + 2.6 = 4.2 \text{ N/mm}^2$. 

Gross stress at level of Cable-4 = 12.4 N/mm². 
Bending moment due to D.L. of girder = 232KNm. 
Net stress at the level of Cable-4 at construction, $\sigma_{c1}=12.4 - 5.4 = 7.0 \text{ N/mm}^2$. 

Volume 5 Issue 8, August 2016 
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Paper ID: ART20161395 
1966
Net stress at the level of Cable-4 at opening to traffic, $\sigma_{c2} = 4.6 \text{ N/mm}^2$.

Net stress at the level of Cable-4 at long term, $\sigma_{c3} = 4.6 \text{ N/mm}^2$.

Secant modulus of elasticity of concrete $E_{cm} = 33 \times 10^3 \text{ N/mm}^2$.

Tangential modulus of elasticity of concrete $E_c = 1.05 \times E_{cm} = 34.70 \times 10^3 \text{ N/mm}^2$.

Loss of prestress at construction, $\Delta \sigma_{cr(t_1)} = \varphi(t_1) \frac{\sigma_{c2} E_p}{E_c} = 19.00 \text{ N/mm}^2$.

Loss of at opening of traffic, $\Delta \sigma_{cr(t_2)} = \Delta \sigma_{cr(t_1)} + (\varphi(t_2) - \varphi(t_1)) \frac{\sigma_{c2} E_p}{E_c} = 32.00 \text{ N/mm}^2$.

Loss of prestress at long term, $\Delta \sigma_{cr(t_3)} = \Delta \sigma_{cr(t_1)} + (\varphi(t_3) - \varphi(t_1)) \frac{\sigma_{c3} E_p}{E_c} = 55.00 \text{ N/mm}^2$.

Total losses of prestress at Long term

$93 + 46 + 55 = 194 \text{ N/mm}^2$.

7. Results and Discussions

The stress evaluation capability checked by IRC 112:2010 and Bridge Design software, but the results are not same.

When these both results were compared the total stress losses from IRC 112:2010 is 21.23% and the losses from Bridge design software is 26.34%. The various stress losses in each points are shown in below table.

Table 4: Single profile stress variation due to one end stressing

<table>
<thead>
<tr>
<th>Length (N/mm²)</th>
<th>Initial Stress</th>
<th>Stress losses from IRC 112:2010</th>
<th>Stress losses from Design Software</th>
<th>Total losses</th>
<th>% of Loss</th>
<th>Total losses</th>
<th>% of Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>1405.26</td>
<td>259.68</td>
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<td>246.69</td>
<td>17.5424</td>
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<td>18.0504</td>
<td>257.403</td>
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<td>2.5</td>
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<td>3.8</td>
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<td>18.5585</td>
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<td>18.7636</td>
<td>269.06</td>
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<td>19.31</td>
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<td>18.8933</td>
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<td>8.8</td>
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<td>276.21</td>
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<td>19.6525</td>
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<td>19.81</td>
<td>278.55</td>
<td>19.8175</td>
<td>283.13</td>
<td>20.2711</td>
</tr>
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</table>

Table 5: Multiple profile stress variation due to one end stressing

<table>
<thead>
<tr>
<th>Length (N/mm²)</th>
<th>Initial Stress</th>
<th>Stress losses from IRC 112:2010</th>
<th>Stress losses from Design Software</th>
<th>Total losses</th>
<th>% of Loss</th>
<th>Total losses</th>
<th>% of Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>1405.26</td>
<td>312.36</td>
<td>22.22</td>
<td>296.73</td>
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<td>1.3</td>
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<td>2.5</td>
<td>1405.26</td>
<td>317.09</td>
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<td>21.91</td>
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<td>316.68</td>
<td>22.51</td>
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<td>321.30</td>
<td>22.84</td>
<td>321.30</td>
<td>22.84</td>
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<tr>
<td>8.8</td>
<td>1405.26</td>
<td>328.89</td>
<td>23.39</td>
<td>325.27</td>
<td>23.13</td>
<td>325.27</td>
<td>23.13</td>
</tr>
<tr>
<td>10.0</td>
<td>1405.26</td>
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<td>23.56</td>
<td>327.91</td>
<td>23.31</td>
<td>327.91</td>
<td>23.31</td>
</tr>
</tbody>
</table>

Figure 4: Single profile stress variation due to one end stressing

Figure 5: Multiple profile stress variation due to one end stressing

The stress loss from these four cases is plotted in Fig 4 to Fig 5. The percentage difference in stress loss calculated from IRC and Bridge design software is varying from 0.93% at 0m span and 0.2% at 10m span in single cable profile with one end stressing. While in both end stressing the percentage difference is varying from 0.93% at 0m span and 0.58% at 5m span.

The percentage difference in stress loss calculated from IRC and Bridge design software is varying from 1.11% at 0m span and 0.14% at 10m span in single cable profile with one end stressing. While in both end stressing the percentage difference is varying from 1.11% at 0m span and 0.69% at 5m span.

8. Conclusion

In the case of friction losses there is only 1.5% to 2% of stress losses from the friction and wobble effect. It reduces the losses as per the length increases. The loss calculation as per the IRC 112:2010 and the losses from bridge design software are same.

The amount of anchorage losses depend upon the slippage of the wire. Normally 5.5% to 6% stress will be loss. In the case of anchorage losses there is some difference in both manually and software stress losses. The design software found the loss value in a different way. Here when the losses will decreases with respect the length of profile increases.
There are no elastic deformation losses by the absence of multiple cables tendon profile. But in the software there having shown the losses due to elastic shortening of cables.

The major part of stress will be losses due to the relaxation of steel. In the case of normal relaxation 2.09% of stress wills loss after the immediate losses. When the stress transfer stage it having only 1.22% of stress losses and the opening traffic having 2.75% of stress will be losses. After a long time that is $\Delta$ days the maximum stress loss will be 7.5%.

Shrinkage of concrete 3% to 4% stress will be loses. The Perimeter of the girder, Relative humidity and grade of cement are the major parts that affect the shrinkage losses.

The creep reduces about 3.5% to 4.5% stress. The Perimeter of the girder, Temperature, Relative humidity and grade of cement are the major parts that affecting the creep. If the small change in RH there will be a huge change in the stress variation. As per IRC112:2010, more than 40 degree the creep coefficient increase by 10%. In software have no ability to find the correct creep coefficient value.

References


