COMPARATIVE STUDY OF PRESTRESS LOSSES USING VARIOUS INTERNATIONAL CODES OF PRACTICES

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ABSTRACT:

There are six types of prestress losses experienced in post-tensioned I-beam girder. In this study, different types of prestress losses calculated from international codes were determined such are BS 8110: 1997, AS 3600: 2001, Eurocode 2: Part 1.1: 1995 and ACI-318: 1994. A step by step calculation of prestress losses as given in the above-mentioned international codes were carried out using a specific prestress I-beam girder. The results of the calculation were analyzed and presented in various perspectives. The differences of losses calculations obtained from the four international codes requirements are examined. Discussion on the differences caused by different prestress losses parameters used and various design considerations adopted are compiled. The effects of prestress losses on Magnel diagram are also investigated in this study. It is found that higher prestress losses will result in larger amount of prestressing tendons to be provided in a post-tensioned I-beam girder as shown by calculations in accordance to provisions given in these four international codes.

Key words: Prestress Losses, Magnel Diagram, International Codes of Practices, Coefficient of Short-term Losses, Coefficient of Long-term Losses

1 INTRODUCTION

The subject of prestress losses is part of the important element in prestress design. Although it has been long time established, the approaches for consideration of prestress losses computation vary amongst present international codes, specifications, and standards throughout the world. Furthermore, numbers of calculation method have been proposed in various literatures on prestress losses, some of them have subtle differences and implications with regard to their applications. This studies present comparison of the approaches for the computation of prestress losses and its effect on the feasible domains specified in present British, Australian, European and American limit states design codes.

The discussion is focused on the prestress losses calculation of a specified post-tensioned I-beam girder section loaded with specific live loads and dead loads as well as self-weight. Computation of six prestress losses i.e. elastic shortening, anchorage seating, friction, creep, shrinkage and steel relaxation using four international codes are carried out. These four international codes are BS 8110: 1997, AS 3600: 2001, Eurocode 2: Part 1.1: 1995, ACI-318: 1994. Coefficient of short-term losses (n_i) and long-term losses (n_L) will be determined. Magnel diagrams will be drawn in accordance to provisions given in these four international codes. Results of the analysis are discussed accordingly and parameters caused the differences will be identified. Conclusion on conservative and economics measures will be drawn.

2 METHODOLOGY

2.1 Calculation sequences and analysis procedures

In order to calculate the prestress concrete design of I-beam girder using different international code, a simple design procedure is used in this study. First of all, tendon and concrete properties recommended in different international codes need to be calculated. These materials properties vary slightly from one code to the others. They are modulus of elasticity for prestressing steel and concrete, initial prestressing force, area of prestressing steel, percentage of relaxation, modular ratio and others. Then, loadings need to be calculated. These include live loads and dead loads. It has to be noted that the same amount of loadings are to be applied in prestress concrete design using the four international codes.

Later, the allowable and permissible stresses at concrete extreme top and bottom fibers are to be determined. There are altogether four permissible stresses of which two stresses are used in initial most severe loading stage and the remaining two stresses are used to control the final most severe loading stage. These stresses have specific provision in all international codes and the values may fluctuate between 2 N/mm^2 to 5 N/mm^2.

The following step is to compute the minimum moment and maximum moment. These moments depend on the values of applied live loads and dead loads at initial loadings and final loadings respectively. Same amount of specific live loads and dead loads were to be imposed on a standard dimension of post-tensioned I-beam girder. This was to maintain the uniformities of loadings and beam section properties so that the end-results of the analysis were not influenced by these two parameters. In post-tensioned beam, the tendon profiles are parabolic in shape, in some cases, the computation of both minimum and maximum moment are in the function of the beam distance, (x). As a result, all calculations by these international codes will share the same amount of minimum moment (M_{min}) and maximum (M_{max}) due to the same loadings during analysis stage.

By using trial and error method, I-beam girder section to be used in prestress losses calculation for all international codes was chosen. Z_t and Z_b of the section should exceed the $Z_{t\ required}$ and $Z_{b\ required}$, respectively. It is to be noted that different international code will have different requirement of $Z_{t\ required}$ and $Z_{b\ required}$. Initially, fix amounts of prestressing steels are to be assumed in the I-beam girder. However, in the latter stage, the prestressing steels provided after appropriate analysis will vary from code to code.

After executing all the above preliminary task, the necessary numerical data collected will be sufficient enough to carry out prestress losses computation as follow. There are altogether six prestress losses that need to be taken into consideration in post-tensioned beam analysis; they are elastic shortening loss, anchorage seating loss, friction loss, creep loss, shrinkage loss and steel relaxation loss. All four international codes chosen in this analysis have their own ways of prestress losses calculation as specified in their respective codes. Some of the calculations are similar to each other, while others may vary in great extent.

The next steps are to obtain the short-term coefficients and long-term coefficients as an output result of calculation by four international codes. These coefficients, again, will vary amongst calculation between these codes. It is universal known that four inequality equations are needed to construct Magnel diagram to determine the prestressing steel required. Since there exist differences in four international codes provision for drawing Magnel diagram, four Magnel diagrams will be drawn separately following provisions in the four international codes.

Finally, all results, numerical values, graphs, tables and graphic representation will be collected and a summary of analysis results will be presented. The effect of prestress losses on the Magnel diagram will be studied and suitable conclusion will be drawn thereafter.

Appropriate discussions based on the results are prepared. Some prominent parameters that contributed to output differences would be identified and generalized conclusion on conservativeness, economics measures will be drawn eventually.

3 ANALYSIS

As shown in Figure 1, elastic shortening loss calculated using formulas given by four international codes were at the range between 32.41 MPa to 36.55 MPa or approximate 3% loss of the initial prestress value. More specifically, elastic shortening loss calculated using provision given in Eurocode 2: Part 1.1: 1995 gave the lowest value which was 32.41 MPa (2.41% loss of initial prestress value). This figure was followed by a much higher loss value of 33.60 MPa (2.43% loss of initial prestress) computed in accordance to provision given in AS 3600: 2001 codes of practices. Computation using provision given in BS 8110: 1997 gave 36.55 MPa or 2.75% elastic shortening loss. Calculation by ACI-318: 1994 recorded elastic shortening loss of 35.19 Mpa or 2.71 % loss.

Referring to Figure 2, for anchorage seating loss, calculation using provision given in BS 8110: 1997 and AS 3600:2001 recorded the highest value which was 97.50 MPa or 7.34 % loss. This was followed by computation by Eurocode 2: Part 1.1: 1995 and ACI-318: 1994 where both codes shared the same figure of 95.00 MPa or 7.32 % loss.

In the case of friction loss, as shown in Figure 3, computation using provision given by the four international codes in unit MPa and percentage arranged in ascending manner were describe in the following line. Computation by ACI-318: 1994 gave 129.73 MPa or 10% friction loss. Calculation using Eurocode 2: Part 1.1: 1995 recorded 137.49 MPa friction loss or 10.24% loss. A much higher friction loss figure was computed by using BS 8110: 1997 and AS 3600: 2001 where both codes produced approximated 11% friction loss.

In addition, creep loss computed using AS3600: 2001 code requirements produced the highest value of 121.65 MPa or 8.82% loss as depicted in Figure 4. The lowest creep loss value was 102.16 MPa or 7.61% loss which was recorded from computation using Eurocode 2: Part 1.1: 1995. The intermediate value were 7.98% creep loss and 8.68% creep loss which were calculated in accordance to provision given in BS 8110: 1997 and ACI-318: 1994 respectively.

Furthermore, shrinkage loss only contributed 1% to 4% loss of the initial prestress. This is shown in Figure 6. Shrinkage loss computed using provision given in ACI-318: 1994 code requirements produced the lowest shrinkage loss of 25.33 MPa or 1.95% loss. Computation using BS 8110: 1997 code requirements gave a higher value of 34.13 MPa or 2.57% loss. AS 3600: 2001 gave 54.47 MPa or 3.95% loss. Eurocode 2: Part 1.1: 1995 gave the highest shrinkage loss value amongst these four codes with 57 MPa or 4.24% loss.

Lastly, by referring to Figure 5, steel relaxation loss contributed 3% to 5% loss of initial prestress. In term of percentage loss, the exact figure were 3.64% loss, 3.94% loss, 4.35% loss and 5.25% loss computed using provision given by ACI-318: 1994, AS 3600: 2001, Eurocode 2: Part 1.1: 1995 and BS 8110: 1997 respectively.

3.1 Total Prestress Losses, Coefficient of Short-term and Long-term Analysis

Amongst the four international codes, calculation using provision given by BS 8110: 1997 codes requirements recorded the highest total prestress losses of 36.89% loss. This was followed by the second highest total prestress losses value of 36.81% loss computed in accordance to provision given in AS 3600: 2001. Calculation following Eurocode 2:Part 1.1: 1995 and ACI-318: 1994 codes requirements produced total prestress losses value of 35.92% loss and 34.30% loss respectively.

As shown in Table 1, the coefficient of short-term losses calculated following codes requirements of the four international codes produced a same constant value of 0.80. The coefficient of long term losses was 0.63 as a result of calculation using provision in both BS 8110: 1997 and AS 3600: 2001. Computation in accordance to Eurocode 2: Part 1.1: 1995 and ACI-318: 1994 codes requirements recorded coefficient of long term losses of 0.64 and 0.66 respectively.

3.2 Magnel diagram analysis

Referring from Figure 7 to Figure 10 and Table 2, it was known that construction of Magnel diagram in accordance to provisions given in BS 8110: 1997 and AS 3600:2001 required high prestressing forces of 4545.5 kN and 4761.9 kN respectively. It was noted that this two codes needed 36 numbers of 12.9 diameter tendons to be provided in the post-tensioned I-beam girder. In addition, analysis on Magnel diagram drawn in accordance to provisions given in Eurocode 2: Part 1.1: 1995 and ACI-318: 1994 codes required a smaller amount of prestressing forces, i.e. 4347.8 kN and 4166.7 kN respectively. A total amount of 34 numbers of 12.9 mm diameter tendons were needed in the post-tension I-beam girder following requirements in Eurocode 2: Part 1.1: 1995 and ACI-318: 1994 codes of practices.

Table 1. Coefficient of short-term and long-term losses calculate in accordance to provisions given in four international codes.

	BS 8110: 1997	Eurocode 2 Part 1.1	AS 3600: 2001	ACI 318: 1994
Δf_{pES} (%)	2.75	2.41	2.43	2.71
Δf_{pA} (%)	7.34	7.07	7.07	7.32
Δf_{pF} (%)	11.00	10.24	10.60	10.00
Δf_{pCR} (%)	7.98	7.61	8.82	8.68
Δf_{pSH} (%)	2.57	4.24	3.95	1.95
Δf_{pR} (%)	5.25	4.35	3.94	3.64
Δf_{Total} (%)	36.89	35.92	36.81	34.30
η_i	0.80	0.80	0.80	0.80
η_L	0.63	0.64	0.63	0.66

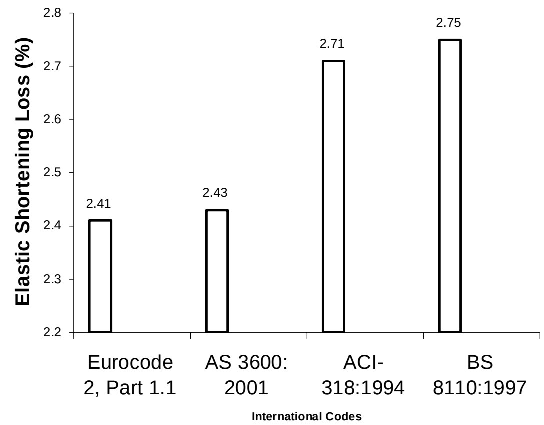


Figure 1. Elastic shortening loss (%) calculation results using 4 international codes.

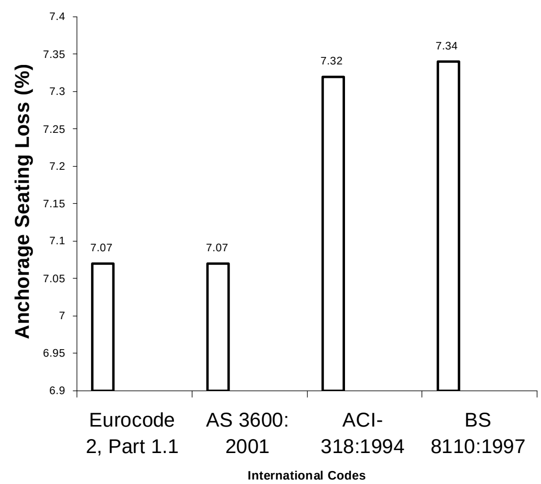


Figure 2. Anchorage seating loss (%) calculation results using 4 international codes.

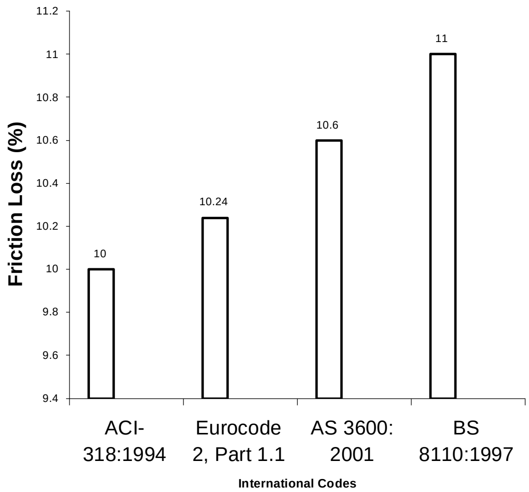


Figure 3. Friction loss (%) calculation results using 4 international codes.

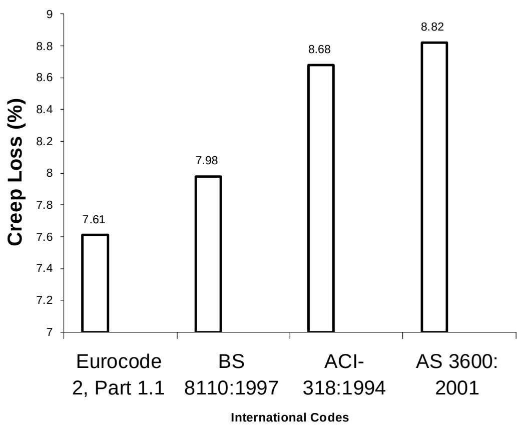
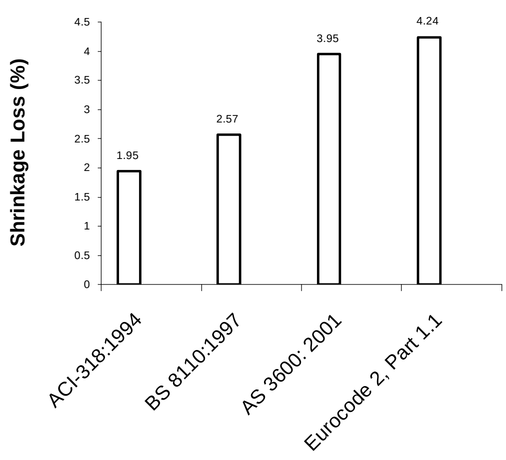


Figure 4. Creep loss (%) calculation results using 4 international codes.



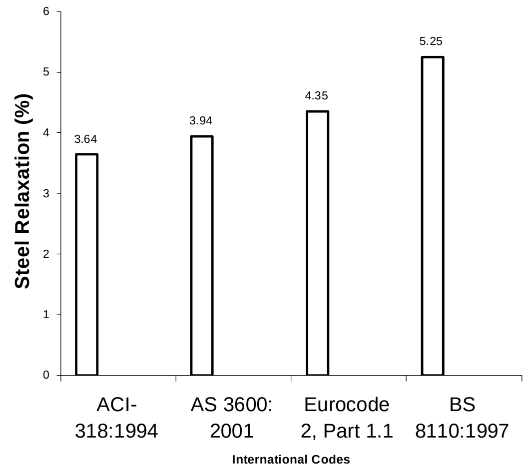


Figure 5. Steel relaxation (%) calculation results using 4 international codes.

Figure 6. Shrinkage loss (%) calculation results using 4 international codes.

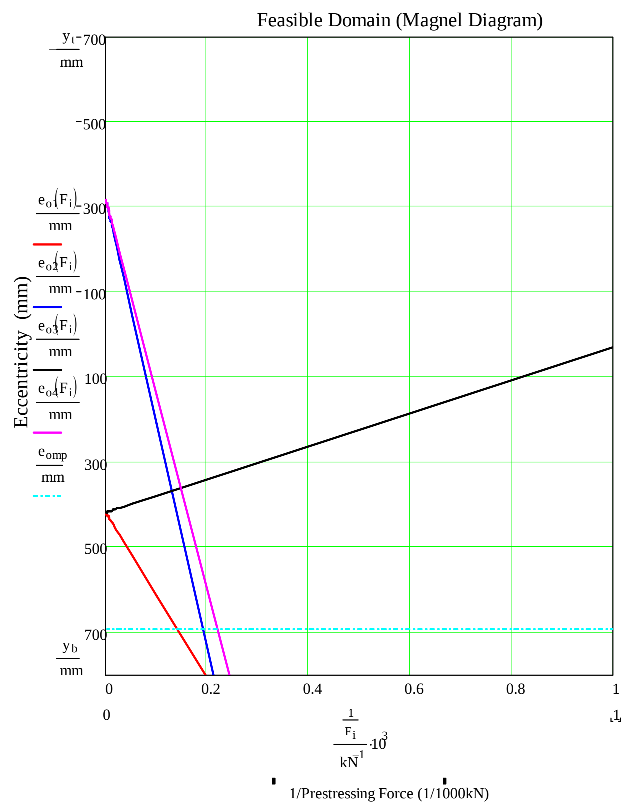


Figure 7. Feasible domain (Magnel Diagram) drawn in accordance to provision given in BS 8110: 1997

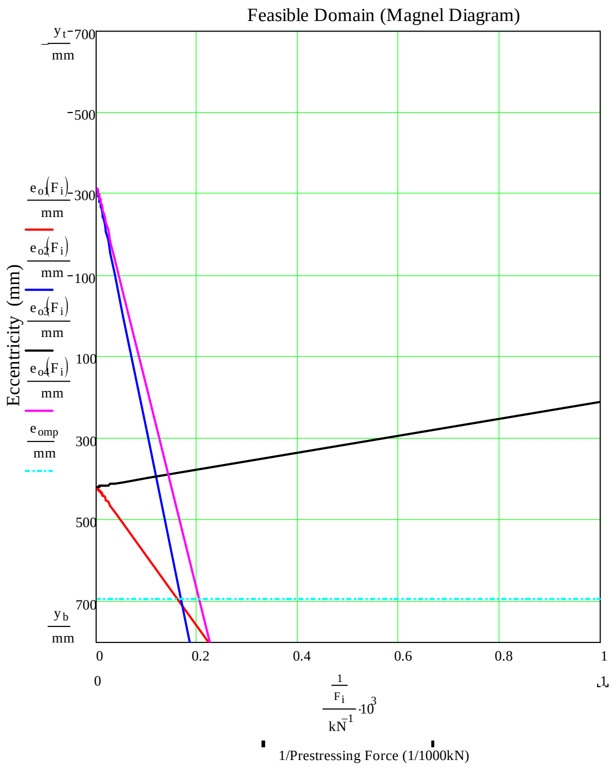


Figure 8. Feasible domain (Magnel Diagram) drawn in accordance to provision given in AS 3600: 2001

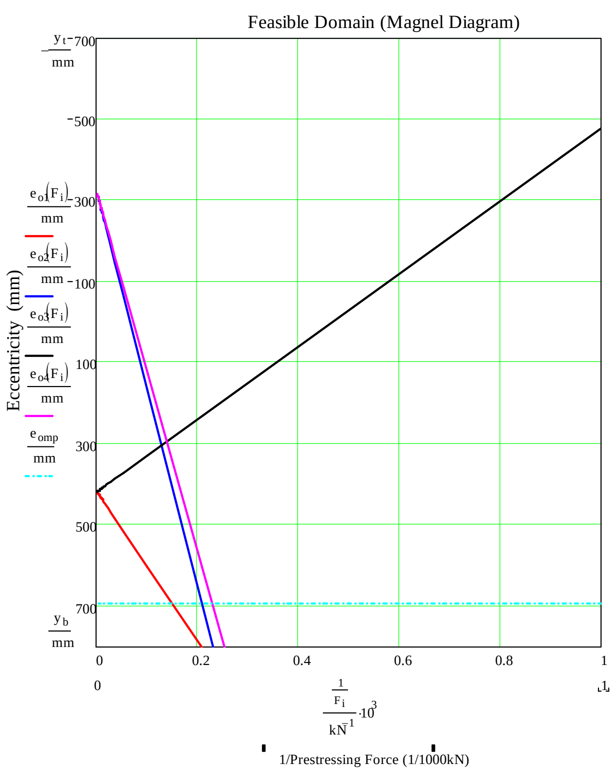


Figure 9. Feasible domain (Magnel Diagram) drawn in accordance to provision given in Eurocode 2: Part 1.1: 1995

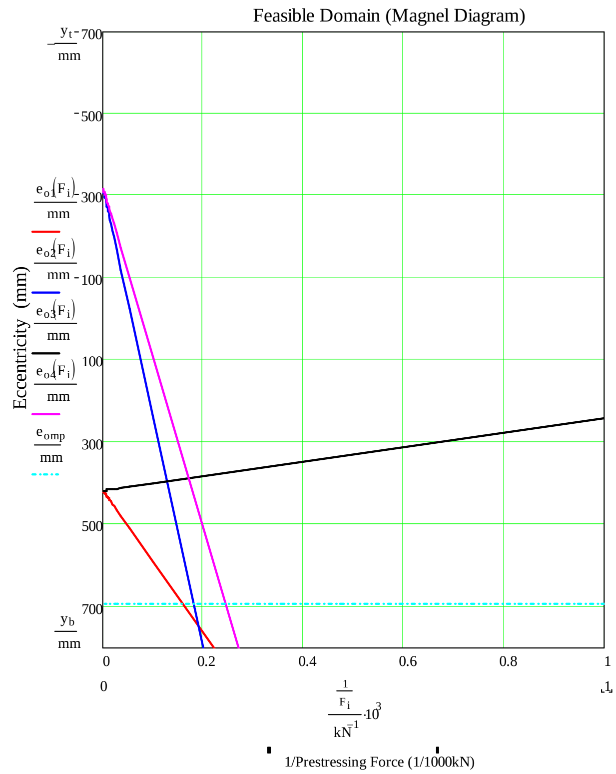


Figure 10. Feasible domain (Magnel Diagram) drawn in accordance to provision given in ACI 318: 1994

Table 2. Summary of Magnel Diagram extracts for four international codes of practices

	BS 8110: 1997	Eurocode 2 Part 1.1	AS 3600: 2001	ACI 318: 1994
P_{req} (kN)	4545.5	4347.8	4761.9	4166.7
Tendon req.	36	34	36	34
P_{actual} (kN)	4784.4	4566.2	4968	4355.4

4 RESULTS AND DISCUSSION

Basically, all the four international codes are using the same standard formula in elastic shortening calculation. However there are some major causes which contribute to this minor differences in elastic shortening loss. The first parameter of differences is that both BS 8110: 1997 and Eurocode 2: Part1.1: 1995 used materials partial safety factor for prestressing steel of value 1.05 and 1.15 respectively. However, AS 3600: 2001 and ACI –318: 1994 used strength reduction factor of 0.8 and 0.82 respectively. Furthermore, the computation of elastic shortening loss is very much depended on the nominal tensile strength of tendon, initial applied prestressing force and Young's modulus of tendon. Four international codes have different provisions for these areas. For example, nominal tensile strength for prestressing steel is 1860 MPa in accordance to provision given in both BS 8110: 1997 and Eurocode 2: Part 1.1: 1995. However, AS 3600: 2001 and ACI-318: 1994 give values of 1840MPa and 1861.2 MPa respectively. The Young's modulus of prestressing steel specified in BS 8110: 1997 and AS 3600: 2001 is 195 MPa while both Eurocode2 and ACI 318 give 190 MPa. The difference of these materials properties are probably due to different methods adopts in laboratory research and testing by different country. Further in depths studies also reveal that the conservative measures provided by the four international codes on initial prestressing forces are not the same. As far as this particular design example is concerned, the initial prestressing forces given by the four international codes are BS 8110: 1997 (4517 kN), AS 3600: 2001 (4692 kN), Eurocode (3970.61 kN), and ACI 318: 1994 (4353.7 kN).

The factors contributing to slight fluctuation in prestress forces given by the four international codes is most probably due to different material properties constants adopted. Furthermore, through extensive laboratory research and advices from a team of expertise in prestress concrete industry, the four international codes drafting committee may implement different conservative measures in initial prestressing forces to suit the construction environment practice in that country.

Different consideration in design parameters adopted by these four international codes as discussed above results in four different modular ratios. The modular ratio become the main parameter governing the slight differences in values of elastic shortening computation provided by the four international codes. It should be noted that the four international codes have their standard requirements of concrete test. Concrete strength test result given by cube size of 150mm x 150mm x 150mm is to be referred by BS 8110: 1997 for prestress losses calculation. However, SAA Australian Standard, AS 3600: 2001 only accepts test results of cylinder with 150mm diameter x 300 mm height. Both above-mentioned cylindrical and cube test results are permitted in Eurocode 2 for prestress losses calculation. Cylinder size of 6 in. diameter x 12 in. heights are to be used for concrete compressive test following provision given in ACI-318: 1994 code requirements. The compressive strength of cylinder is to be given in unit pound per square inch (psi) since almost all parameters to be input into ACI-318 prestress losses equations are in unit psi. The four international codes have different Young's modulus of concrete at 7days. This is due to different equations used in calculation of 7 days Young's modulus by the four international codes of practices. This results in varying modular ratio calculation. The above-mentioned reasons are some major contribution for the small differences in elastic shortening loss calculation.

Apart from this, all the four international codes are using the same standard formula in anchorage seating loss computation. However, since these four international codes adopt different material properties calculation, it results in minor differences in anchorage seating loss computation.

The major causes of the minor difference are that all the four international codes suggest friction loss formulas with some kind of differences. Furthermore, wobble coefficient adopt by BS 8110: 1997 standard, Eurocode 2 and ACI-318 have significant differences in numerical values in order to suit the different formulas used by these codes. The wobble coefficient supplied by these three international codes are BS 8110: 1997 (33×10^{-4}), Eurocode 2 (0.015) and ACI-318 (0.002). The reasons for the differences formulas and design parameters used in friction loss calculation may be explained as follow. Great efforts through research and development in the formulation of appropriate friction loss equations may have been carried out in different country in the past decades. All codes drafting committees may adopt their own laboratory testing procedure on friction loss and produce unique design equation for friction loss. It should be noted that the formation of different types of friction loss equations may be a combination of extensive discussion in a team of expertise and laboratory testing results.

However, although totally different formulas adopted by these four international codes, there is only 1% different of friction loss between the highest values (given by BS 8110: 1997 for this particular design example) and the lowest values (recorded by ACI-318: 1994). This 1% loss difference is considered small and negligible since it doesn't have much effect on the final prestress losses coefficient computation. Instead of wobble coefficient, SAA Australian standard, AS 3600: 2001 use angular deviator as one of the coefficients in friction calculation. On the other hand, there is a similarity in friction loss calculation between these four international codes whereby they follow the same procedure in obtaining the value of aggregate change in slope.

Thorough studies of different design consideration by all the four international codes found out that there are some different design parameters adopted by all these international codes which cause the small differences in creep loss computation. Both BS 8110: 1997 and Eurocode 2: Part 1.1: 1995 standards use effective section thickness while SAA Australian Standard, AS 3600: 2001 use hypothetical thickness of I-beam girder section to obtain respective creep coefficients and design creep factor. The difference of about 84 mm between these two types of thickness is recorded. The causes of this differences in section thickness are that all the above-mentioned codes use different design charts to obtain necessary creep coefficient (adopt in BS 8110: 1997 and Eurocode 2) or design creep factor (adopts in AS 3600: 2001) where appropriate. However, it is worth to mention here that both BS 8110: 1997 and Eurocode 2: Part 1.1: 1995 standard need ambient relative humidity to obtain relevant creep coefficient. Meanwhile, the design chart provided by SAA Australian Standard, AS 3600: 2001 does not require relative humidity information. However, user needs to choose one of the four categories of climate environments in order to obtain interpolation results of design creep factor. ACI-318: 1994 does not use any of the above-mentioned thickness for creep loss calculation. Besides, it is to be noted that ACI-318: 1994 codes eliminate all the above tasks of finding creep coefficient by introducing Specific Creep Factor of 2.0 and 1.6 for pre-tensioned and post-tensioned members respectively. There is one similarity of creep loss calculation using the four international codes. These four international codes accept the same standard formula for calculation of critical stress which become one of the main parts in obtaining creep loss value. However, these calculated value of critical stress vary from code to code due to different consideration in materials properties.

Finally, it is noted that there are four different set of formulas provided by these four international codes on creep loss calculation. These prestress creep loss equations may have been formed through combination of extensive laboratory research and theoretical improvements in this particular area. Furthermore, the code drafting committees with consultation from industry's expertise and appropriate meetings, discussions, debates and so on conducted in each individual country may have brought to different formulation of creep loss equations by these four international codes. As a result, the computed value of creep loss in accordance to the four international codes requirements may exhibit some kind of differences. However, as far as this design example is concerned, the differences between the highest creep loss value (computation through AS 3600: 2001) and the lowest creep loss values (computation through Eurocode 2) is about 1.21%. This considerably small creep loss differences may have very little effect on the short-term and long-term prestress losses coefficients for the four international codes.

Shrinkage loss calculation is quite straightforward in the four international codes. The design parameters required is not much differ from those needed in creep loss calculation such as effective section thickness adopt by BS 8110: 1997 and Eurocode 2: Part 1.1 1995, hypothetical thickness adopts by AS 3600:2001, ambient relative humidity and the four climate conditions which have already discuss earlier in creep loss calculation. It is worth to mention here that all the three codes except Eurocode 2: Part 1.1 : 1995 have specific conservative value of basic shrinkage strain of concrete. AS 3600: 2001 code requires one additional parameter which is shrinkage strain coefficient. Manual calculations are needed for final shrinkage strain using the above-mentioned parameter following designated formula given by BS 8110:1997, AS 3600: 2001 and ACI-318: 1994. Final shrinkage strain could be obtained through interpolation of shrinkage graph for shrinkage loss calculation following Eurocode 2: Part 1.1: 1995 code requirements which eliminate the task of manual calculation and the value is much conservative. As discussed earlier in previous few sections, the different types of design charts for shrinkage loss provide by the four international codes and involvement of various design parameters may due to the facts the all the four international codes drafting committees have different ways of shrinkage loss calculation.

Some parameters which cause the small differences in steel relaxation loss. It is known that BS 8110: 1997 and Eurocode 2: Part 1.1: 1995 provide numerical data for maximum steel relaxation after 1000-hours (in %), while AS 3600: 2001 and ACI-318:1994 standard do not have provisions for this. Instead, calculations following AS 3600: 2001 requirements need to obtain duration coefficient, stress coefficient, and annual temperature function beforehand. On the other hand, provision in ACI-318: 1994 introduce a different formula which is the reduced initial prestress and yield strength required. Again, the reasons contribute to the above totally different equations used are almost the same as previous sections whereby the codes drafting committee may rely on the recommendation from expertise and laboratory testing results.

The total prestress losses for calculation in accordance to four international codes are tabulated in Table 1. BS 8110: 1997 records the highest prestress losses of 36.89 %. This is followed by prestress losses calculation by AS 3600: 2001 (36.81 % loss), Eurocode 2, Part 1.1: 1995 (35.92 % loss) and ACI 318: 1994 (34.3 % loss).

5 CONCLUSION

Conclusion on comparative studies of prestress losses calculations in accordance to the four international codes, namely BS 8110: 1997, AS 3600: 2001, Eurocode 2: Part 1.1: 1995 and ACI- 318: 1994 can be listed down as follow:

a) Prestress losses calculations following provisions given in BS 8110: 1997 codes requirements may produce the highest values in term of percentage on elastic shortening loss, friction loss, anchorage seating loss and steel relaxation loss amongst four international codes. BS 8110: 1997 may produce intermediate values in term of percentage on shrinkage loss and creep loss.
b) Prestress losses calculations following provisions in AS 3600: 2001 codes requirements may produce the highest value in term of percentage on creep loss amongst four international codes. AS 3600: 2001 may produce intermediate value in term of percentage on other prestress losses calculation.
c) Prestress losses calculations following provisions in Eurocode 2 code requirements may produce highest shrinkage loss value in term of percentage amongst four international codes. Eurocode 2 may also produce the lowest value in term of percentage on elastic shortening loss, anchorage seating loss and creep loss. For friction loss and steel relaxation loss, it may produce intermediate value in term of percentage.
d) Prestress losses calculations in accordance to provisions given in ACI-318: 1994 code may produce lowest value in steel relaxation loss, shrinkage loss and friction loss. ACI-318: 1994 may produce intermediate values in terms of percentage in other losses.
e) Total prestress losses computed in accordance to provision given in the four international codes supply us an idea that BS 8110: 1997 may produce highest total prestress losses value (36.89% loss in this particular design example). This is followed by AS 3600: 2001 (36.81% loss) and Eurocode 2 (36.92% loss). Computation in accordance to ACI-318: 1994 code provision may produce the least prestress losses value (34.3% loss in this particular design example).
f) The difference between the highest total prestress losses value and the lowest prestress losses value is between the ranges of 2 % – 3 % amongst the four international codes.

g) The reasons contributing to differences in prestress losses calculation may be described as follow. The use of partial safety factors and strength reduction factor interchangeably between the four international codes contribute to slights prestress loss differences. The different values in material properties given by the four international codes as described before also become part of the reasons for differences in prestress losses calculations amongst four international codes.

h) Furthermore, there are a few special design parameters that incorporate by these codes to accommodate certain particular equations and formulas used in prestress losses calculations. These parameters include creep coefficient, creep design factors, wobble coefficient, angular deviation, curvature coefficients, effective section thickness, aggregate change, hypothetical thickness and others. These design parameters vary from one code to the other have some significant contributions in the differences in prestress losses calculation amongst the four international codes.

i) The reasons account for the different types of equations and various types of design parameters use in the four international codes may summarize as follow. Each country has its own policy and rules on the strictness of conservative measures to be endowed in prestress concrete design. This conservative measures are discussed amongst expertise in prestress concrete industry and the codes drafting committees through logical theoretical background. These standard equations, which are different from code to code, are further proven by laboratory researches on prestress losses in each country. These countries may have their own set of laboratory testing equipments and the test results may vary in great extent. This may provide good reasons on why there exist some minor differences in prestress losses calculation amongst these codes.

j) Interpretation of four Magnel diagram drawn in accordance to four international codes requirements provide a logical and affirmative results on the relationship between the prestress losses and the number of tendon provided. A higher prestress losses will cause a larger amount of prestressing steels to be provided. This circumstance can be explained where prestress losses will reduce applied prestress forces, a larger amount of prestressing steels need to be provided to compensate the losses occur.

k) Magnel diagram drawn in accordance to provisions given in BS 8110: 1997 and AS 3600: 2001 may produce the most conservative results whereby more prestressing tendons may need to be provided. On the other hand, prestressed concrete design following provisions given in Eurocode 2: Part 1.1: 2001 and ACI-318: 1994 code of practices may need a smaller amount of prestressing tendons to be provided and these two codes may produce a more economical design.

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