# Computerised Design of Box-Girder Bridge Using Balanced Cantilever Method

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**Keywords:** Computerised design; box-girder bridge; balanced cantilever method.

**Abstract.** This paper present preliminary design procedures of box girder bridge using balance cantilever method by using Microsoft Excel spreadsheet. This paper covered the introduction, objective, scope of study and design specification of box girder bridge using balance cantilever method. Cantilever construction method is adopted and considered in design box girder bridge using balance cantilever method. The spreadsheet focus on design of prestressing cable for box-girder bridge using balanced cantilever method. In design specification, maximum bending moment at pier from construction phase are the concerns since the results to determine prestressed force, number of strand and cable arrangement. The box-girder bridge using balance cantilever method design according to construction phase and loading imposed to the bridge. The output data from post tension prestressed designed are gather in one spreadsheet for reference. Eurocodes BS EN 1992-1-1 and EN 1992-2 are applied throughout the analysis and design procedures of the spreadsheet. The accuracy of the spreadsheet is verified by redesign establish structure and compare the output.

## Introduction

The balance cantilever method is method of construction where the segment is need to construct from pier. Balance cantilever method are suitable for long span bridge especially for crossing wide river and minimize construction site at ground level. Non-composite box girder is commonly use with balance cantilever method. Box girder is a main beams comprise girder in the shape of a hollow box. Various depth of segment can be applying to reduce segment self-weight. During construction phase, construction of box girder need to build symmetrically outwards from the piers to avoid high asymmetric overturning moments in the piers [6]. Post-tension cable is use due to massive structure for box girder need to construct at the site. The bridge consists two type of longitudinal prestressing cable, they are cantilever beam cable placed in the vicinity of the upper flange of box-girder and integration cable placed near the mid span of each span to archive deck continuity and to withstand the resulting bending moments. Negative Moment at the pier increase as the span of the bridge become longer and can be cater by cantilever beam cable. To counter various positive moment at pier due to construction, numbers of tendons are applying at early stage of construction.

Design of box-girder bridge using balance cantilever method are complicated due to many factor have to be consider including section of box-girder, method of construction, loading during construction, traffic load and arrangement of the cable. Usage of software in designing bridge really help the designer. At market, a lot of software application to design bridge such as RM Bridge, LEAP Bridge, CSIBRIDGE and IDS BDS. The application of available analysis and design software usually expensive and very costly to buy on a piece of software that is not use frequently. Certainly, a lot of mathematic equations and repeating calculations are involved during the design stages of post tension cable by using manual calculations. Work load increment due to analysis of different types of load combination cases effect the results of the design too. Hence, time and accuracy factors will become the concerns to obtain the output results. Furthermore, application of practice code of British Standard is no longer relevant in future design. Practice code of Eurocode is used in consideration loading analysis give guidelines to consider parameter use in design bridge.

Searching or refer processes to guidelines of Eurocode 2 can be reduced in order to compute the results which comprises of factors in term of time saving, accurate, economic and safety.

The aims of this project is to develop a series procedure of box-girder bridge using cantilever method design based on prestressed concrete design procedure. Other than that, to develop a spreadsheet for the design of presstressed box-girder bridges using balance cantilever method based on Eurocode 2 to reduce working time.

To archive objective had stated, scope of study had detailed to several scope. Firstly, use cantilever method during construction consider in design the bridge. Pre-stressing method used in post-tension. Thirdly, Eurocode 2 is applied in design process. Only use single box-girder as a deck in cantilever bridge. Finally, produce spreadsheet using Microsoft excel for design and analysis

**Previous Studies**

A comprehensive study about design of box-girder bridge using balance cantilever method [7]. In the thesis discussed the methodology used to design balance cantilever bridge. In the thesis touched on the type of box-girder used for bridge and construction method used for construct bridge using balance cantilever method. Method of construction is main concern in designing balance cantilever bridge where load apply during construction to the structure need to be determine before designing the bridge.

Other study about Conceptual design of long-span cantilever constructed concrete bridges [8]. The thesis discussed on guidelines we need to follow in order to produce a pleasant looking bridge and evaluate cantilever bridge around the world. By using case studies, this thesis discusses on material usage and consequent cost, between bridges built with the main purpose of a good design and bridges built with the main purpose of being economic.

From previous Study, there are some improvements that can be made from the thesis that had successfully published. Deficiencies in the method of recheck to the proposed design is improvement that can be made from the previous studies. Conceptual in term of construction method can be apply in design.

**Research Methodology**

Figure 1 below show methodology used before determine appropriate program can be design.

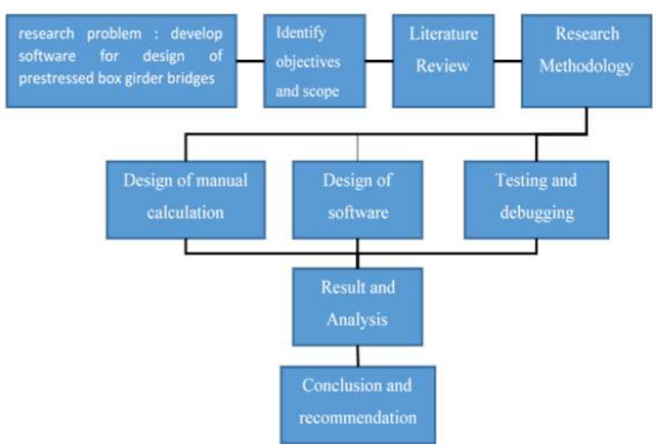



Figure 1: Research Flow Chart

***Flow Chart of Computerized Design of Box-Girder Bridge Using Balance Cantilever Method.***
For ease of understanding and application of the program, general procedures for the software, design cantilever cable and continuity cable shown in Figure 2.

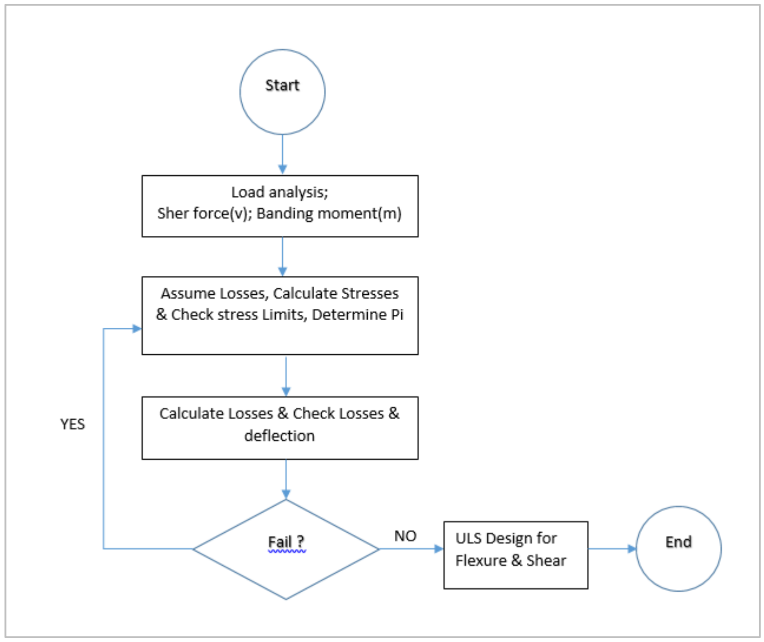



Figure 2: Prestressing Design Procedure

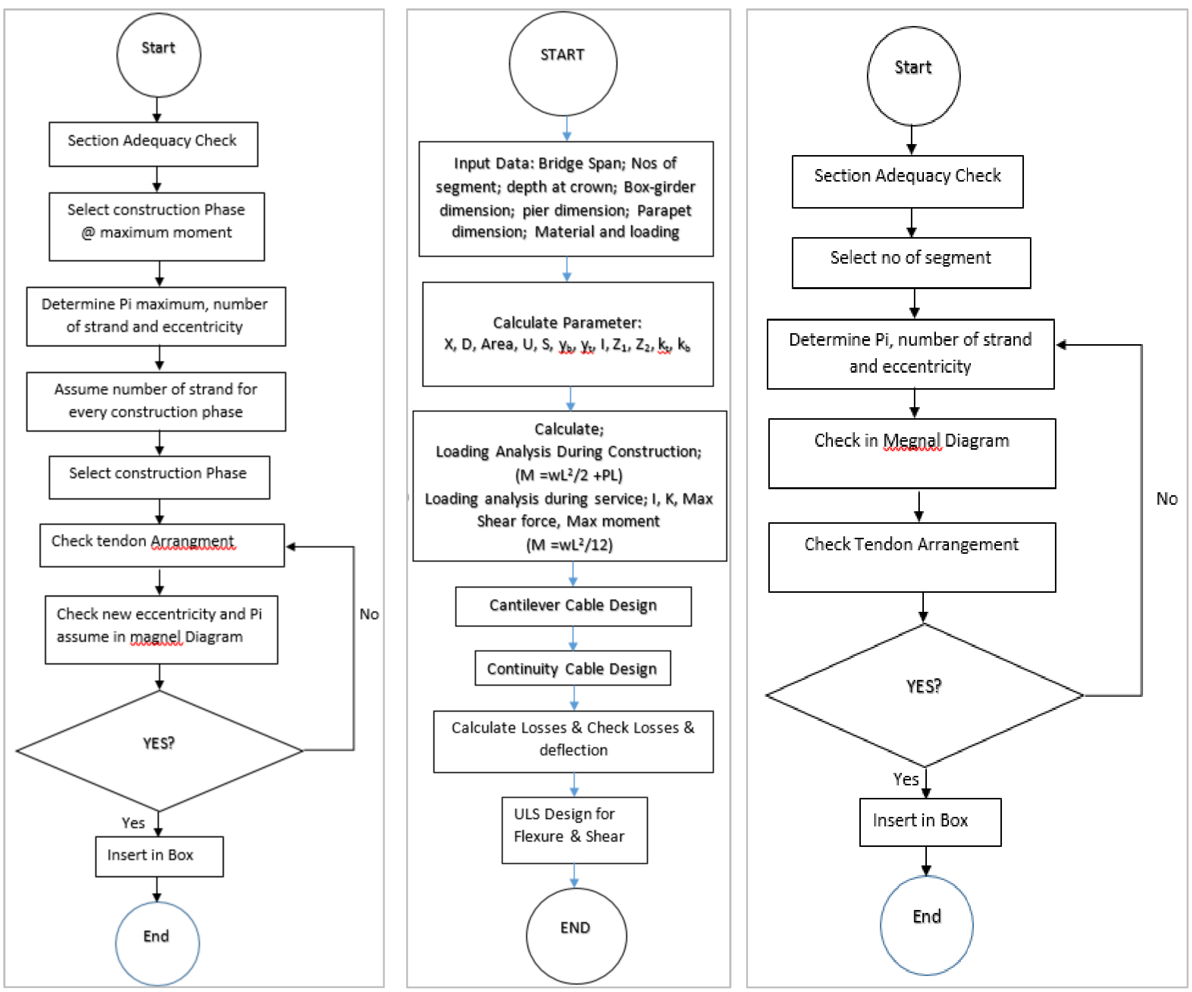



Figure 3: General procedure to design (a) box-girder bridge using balance cantilever method, (b) cantilever cable, and (c) continuity cable design

## Result and Spreadsheet Guidelines

### *BalCal 2.0 Bridge*

'BalCal Bridge 2.0' is the abbreviation for 'Balance-cantilever Bridge 2.0'. The design of the bridge based on Eurocode and it is develop using Microsoft Excel. 'BalCal Bridge 2.0' is a computer program that is able to design bridge the balanced-cantilever method which is based on post-tension beam design with few considerations made specifically for construction method. This computer base program provided with detail calculation and formula use. Its will help the user to recheck if any problem and help the user more understand in designing process.

### *Main Menu*

The computer program will begin with BalCa Bridge 2.0 main menu that can be seen in Figure 4. The main menu has list all section of design which the user can check the button. In main menu have design specification, bridge loading, design analysis, cable design, cable output and help. By clicking cable design button will link to cable design menu where all related design for cantilever cable, continuity cable and design check can be select.


Figure 4: Main Menu

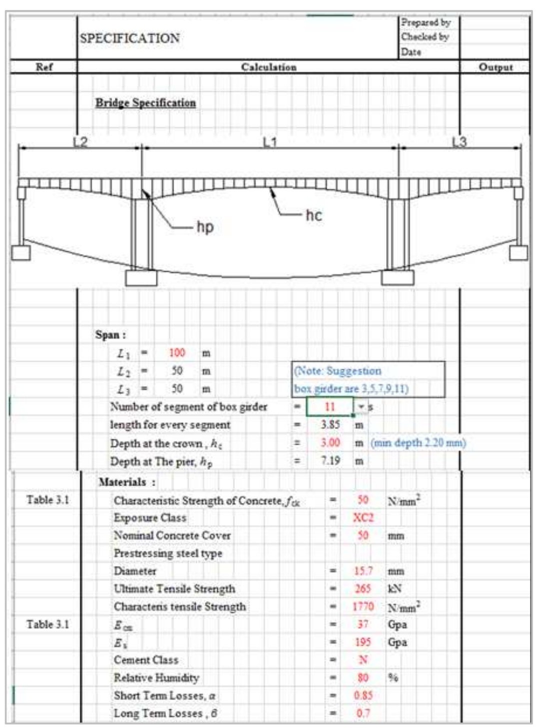



Figure 5: Bridge and Material specification

***Design Specification***

Process of design start with specification where the user clicks on the design specification command button, the user will be redirected to the design specification sheet. Specification sheet divided into three section that are the bridge specification, Dimension of structure and materials properties. For the bridge specification, the user need to insert the value needed by the program such as the length of the main span of the bridge, the height of segment at the crown and select the number of segment that is wanted during construction. Number of segment is limited to 3, 5, 7, 9 and 11.

Other than that, user need to insert dimension of box-girder base on parameter and diagram as reference. After all cross section details of box-girder section have insert, the moment of Inertia, second moment area, neutral axis, the section modulus and perimeter will be calculated automatically for the user. Other than that, the user also required to input the specification of the pier such as height of each pier, length and width of pier. After that cross section details of the parapet need to state by user.

Under the material properties section, users need to state material properties that will used in designing process by selecting or state the value. Properties needed under material properties section such as the strength of concrete used, exposure class of the bridge, concrete cover, diameter of prestressing steel, ultimate tensile strength of prestressing steel, tensile strength of prestressing steel, Elastic modulus of steel and concrete, cement class, relative humidity of the area and also the short term losses and long term losses which need to be assumed by the user.

***Bridge Load***

Under the bridge Loading, Users need to input loading of bridge furniture, premix, traveler and construction load. For second section, traffic loading automatically calculated. Four loading type to consider they are Gr1a, Gr5, Load model 3 and load model 1. User need to select load type to consider in design. Bridge loading can be seen in Figure 6.

***Analysis***

In this spreadsheet divided into two section. They are analysis during construction and during services. The user is not required to insert any input but can check the result of the moment distribution that is done on a different sheet to calculate the different moment and shear forces that are used for design of the bridge. For cantilever analysis. User can click on details calculation button to open detail analysis for cantilever analysis. Loading analysis spreadsheet can be seen in Figure 7.

***Cable Design***

Cable design is a main menu for user before start design for cantilever cable and continuity cable. In this section user able to understand steps in design the cable. Cable design divided two group. They are cantilever cable and continuity cable and losses checking for both cable before can procced to deflection checking, ultimate moment and shear links.

***Section adequacy check***

In section adequacy check, to ensure the section is able to resist the loads and moment induced on it. All parameter such as concrete properties and stress limits are calculate automatically by referring to the data already inserted into the spreadsheet earlier. User need to select Construction phase and segment to check section adequacy. At output column will show “OK!” for Zreq < Z1 or 2 and “REDESIGN!” for Zreq > Z1 or 2. Spreadsheet for section adequacy can be seen in Figure 8.

***Cantilever Cable Design***

In cantilever cable design, construction method taking consider during design cantilever cable design. The concept of the construction is that the bridge is built segmentally or can be call construction phase. The bridge is built segmentally simultaneously in both directions to ensure balance of the structure. The segment’s tendons stressed so that can support the section before next segment can be construct. Hence, the role of the cantilever tendons to support the self-weight of the structure during construction, construction load and facility on the bridge before all the segment connected. In the absence of an external prestressing tendon as is the case here, it will also support the negative moment due to service load at the pier.

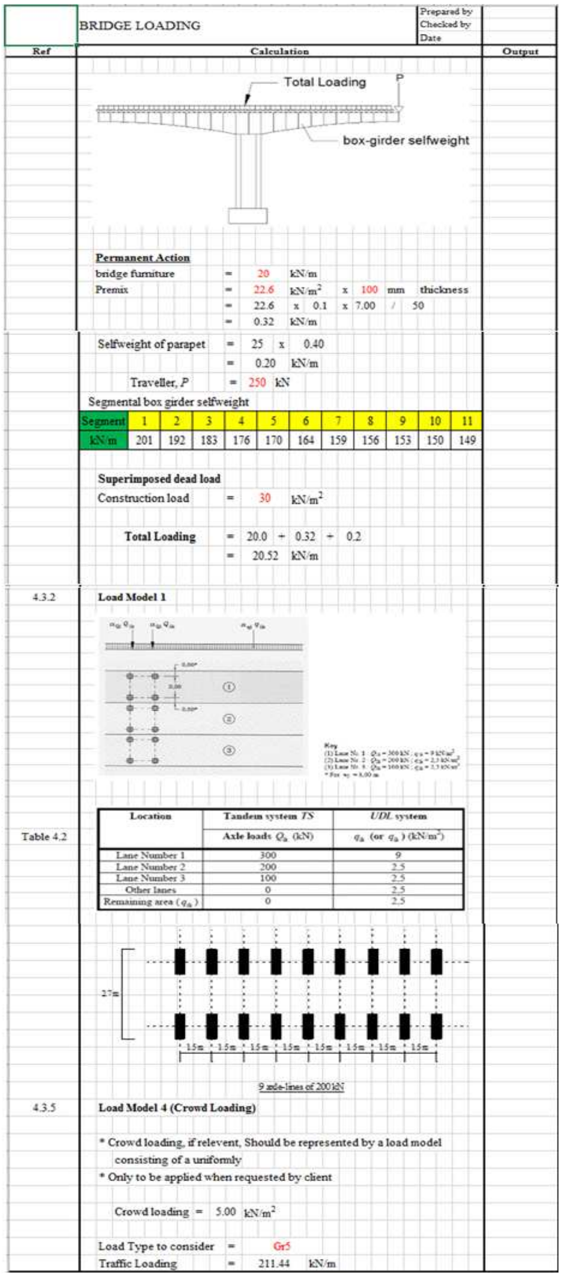



Figure 6: Bridge load

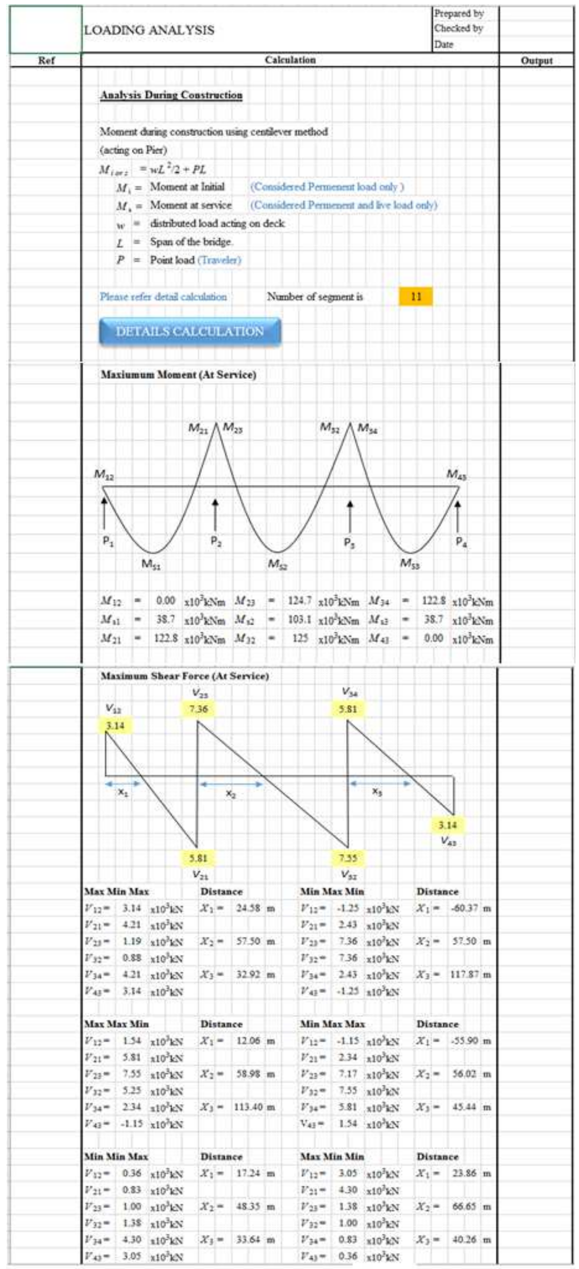



Figure 7: Bridge analysis

In Figure 9 show sheet for design cantilever tendons. Number of segment decided earlier consider as construction phase in cantilever design. User need to choose construction phase before start design the cantilever tendons. User need to select construction phase at highest bending moment. After that, assumption need to be done to determine nominal concrete cover. User need to input diameter of duct, Cmin,dur and diameter of stirrup. Maximum eccentricity automatically calculated. Next, User need to determine minimum prestressing force base on four prestressing force,Pi equation automatically calculate. Magnel diagram used as checking purpose to check minimum prestresing force determine earlier within the range or not. In this part, user need to input maximum eccentricity,e and Prestressing force,Pi. No of strand automatically calculated from Pi had check before.

User need to insert %UTS and Aps. In Figure 9 can see the box with maximum Pi, maximum e, number of strand, suggestion number for every segment and Pi. User need to insert number of strand assume at color box. After that, user need to procced to tendon profile to check eccentricity. For last checking propose, stress limits need to be check. In this part, user doesn't need to insert any value. "OK!" will appear if the stress within the limits f1t, f2t, f1s, f1s and will appear "NOT OK!" if the stress out from the limits.

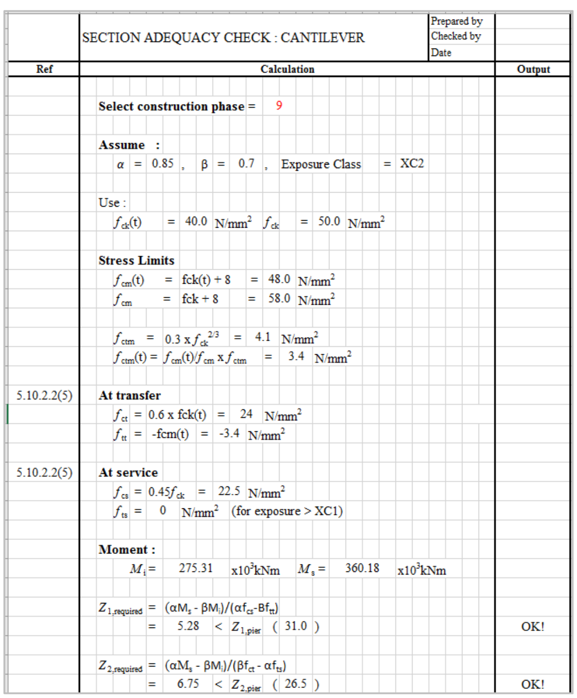
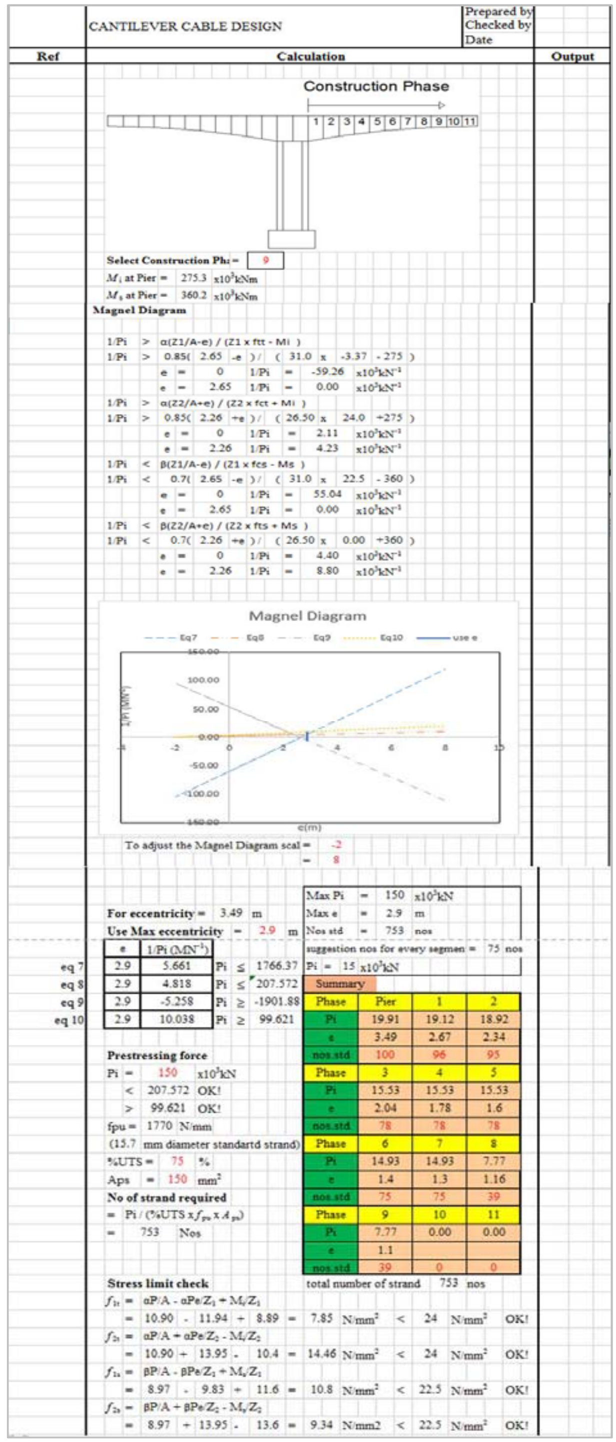



Figure 8: Adequacy check section




| | e | 1/Pi (MN⁻¹) | | |
|---|---|---|---|---|
| eq 7 | 2.9 | 5.661 | Pi ≤ | 1766.37 |
| eq 8 | 2.9 | 4.818 | Pi ≤ | 207.572 |
| eq 9 | 2.9 | -5.258 | Pi ≥ | -1901.88 |
| eq 10 | 2.9 | 10.038 | Pi ≥ | 99.621 |

| Phase | Pier | 1 | 2 |
|---|---|---|---|
| Pi | 19.91 | 19.12 | 18.92 |
| e | 3.49 | 2.67 | 2.34 |
| nos.std | 100 | 96 | 95 |
| Phase | 3 | 4 | 5 |
| Pi | 15.53 | 15.53 | 15.53 |
| e | 2.04 | 1.78 | 1.6 |
| nos.std | 78 | 78 | 78 |
| Phase | 6 | 7 | 8 |
| Pi | 14.93 | 14.93 | 7.77 |
| e | 1.4 | 1.3 | 1.16 |
| nos.std | 75 | 75 | 39 |
| Phase | 9 | 10 | 11 |
| Pi | 7.77 | 0.00 | 0.00 |
| e | 1.1 | | |
| nos.std | 39 | 0 | 0 |

$f_{1t}$ = αP/A - αPe/Z₁ + Mi/Z₁ = 10.90 - 11.94 + 8.89 = 7.85 N/mm² < 24 N/mm² OK!

$f_{2t}$ = αP/A + αPe/Z₂ - Mi/Z₂ = 10.90 + 13.95 - 10.4 = 14.46 N/mm² < 24 N/mm² OK!

$f_{1s}$ = βP/A - βPe/Z₁ + Ms/Z₁ = 8.97 - 9.83 + 11.6 = 10.8 N/mm² < 22.5 N/mm² OK!

$f_{2s}$ = βP/A + βPe/Z₂ - Ms/Z₂ = 8.97 + 13.95 - 13.6 = 9.34 N/mm2 < 22.5 N/mm² OK!

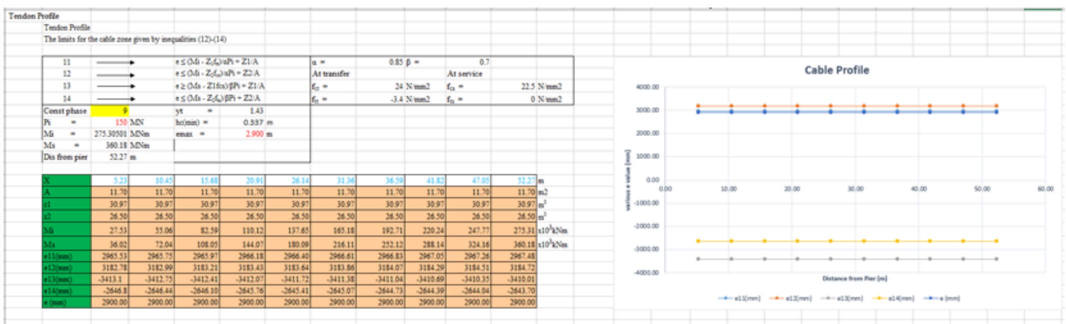
Figure 9: Cantilever Cable Design

***Continuity Cable Design***

The design procedure similar to cantilever cable design. The continuity cable design which is supposed to resist the positive moment due to service load and any positive moment due to structure self-weight once it is joined if there is no external prestressing. For continuity cable design have two design process need to be done for middle span (span 2-3) and outside span (span 1-2&3-4). For middle span, at the crown need to resisting maximum moment. For outside span maximum moment will be at middle of span.

***Tendon Profile***

In tendon Profile sheet, user can check tendon arrangement base on graph provided in the sheet. The tendon arrangement need in the four inequality equation ($e_{11}$, $e_{12}$, $e_{13}$, $e_{14}$). User need insert Pi apply for every construction phase and $e_{new}$. If $e_{new}$ that decide earlier within the four inequality equation, user need to insert eccentricity in color box at cantilever cable design or continuity cable design.


Tendon Profile
Tendon Profile
The limits for the cable zone given by inequalities (12)-(14)

| | | | | | |
|---|---|---|---|---|---|
| 11 | → | e ≤ (Mi - $Z_2 f_{ti}$)/αPi + Z1/A | α = 0.85 | β = 0.7 | |
| 12 | → | e ≤ (Mi - $Z_2 f_{ci}$)/αPi + Z2/A | At transfer | | At service |
| 13 | → | e ≥ (Ms - Z1fcs)/βPi + Z1/A | $f_{ci}$ = 24 N/mm2 | | $f_{cs}$ = 22.5 N/mm2 |
| 14 | → | e ≤ (Ms - $Z_2 f_{ts}$)/βPi + Z2/A | $f_{ti}$ = -3.4 N/mm2 | | $f_{ts}$ = 0 N/mm2 |

| | | | |
|---|---|---|---|
| Const phase | 9 | yt = | 1.43 |
| Pi = | 150 MN | hc(min) = | 0.337 m |
| Mi = | 275.30501 MNm | emax = | 2.900 m |
| Ms = | 360.18 MNm | | |
| Dis from pier | 52.27 m | | |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| X | 5.23 | 10.45 | 15.68 | 20.91 | 26.14 | 31.36 | 36.59 | 41.82 | 47.05 | 52.27 | m |
| A | 11.70 | 11.70 | 11.70 | 11.70 | 11.70 | 11.70 | 11.70 | 11.70 | 11.70 | 11.70 | m2 |
| z1 | 30.97 | 30.97 | 30.97 | 30.97 | 30.97 | 30.97 | 30.97 | 30.97 | 30.97 | 30.97 | $m^3$ |
| z2 | 26.50 | 26.50 | 26.50 | 26.50 | 26.50 | 26.50 | 26.50 | 26.50 | 26.50 | 26.50 | $m^3$ |
| Mi | 27.53 | 55.06 | 82.59 | 110.12 | 137.65 | 165.18 | 192.71 | 220.24 | 247.77 | 275.31 | $x10^3$kNm |
| Ms | 36.02 | 72.04 | 108.05 | 144.07 | 180.09 | 216.11 | 252.12 | 288.14 | 324.16 | 360.18 | $x10^3$kNm |
| e11(mm) | 2965.53 | 2965.75 | 2965.97 | 2966.18 | 2966.40 | 2966.61 | 2966.83 | 2967.05 | 2967.26 | 2967.48 | |
| e12(mm) | 3182.78 | 3182.99 | 3183.21 | 3183.43 | 3183.64 | 3183.86 | 3184.07 | 3184.29 | 3184.51 | 3184.72 | |
| e13(mm) | -3413.1 | -3412.75 | -3412.41 | -3412.07 | -3411.72 | -3411.38 | -3411.04 | -3410.69 | -3410.35 | -3410.01 | |
| e14(mm) | -2646.8 | -2646.44 | -2646.10 | -2645.76 | -2645.41 | -2645.07 | -2644.73 | -2644.39 | -2644.04 | -2643.70 | |
| e (mm) | 2900.00 | 2900.00 | 2900.00 | 2900.00 | 2900.00 | 2900.00 | 2900.00 | 2900.00 | 2900.00 | 2900.00 | |



Figure 10: Tendon Profile Arrangement

***Losses***

At the beginning of design, user need to assume the value for short term and long term losses. In this section, the losses are check to ensure that they do not exceed the value set by the user. Losses in prestressing occurs due to two type of losses, they are short term losses and long term losses. In short term losses have elastic shortening which shortening of the prestressing steel, friction between the tendons and the tube housing it, enchorage draw in. For long term losses, shrinkage of concrete over time which is due to compressive force that acts on the concrete which compacts it hence causing shrinkage, relaxation of steel occurs as time goes on due to sustain force under tension which steel adapts to as time goes on and creep of concrete which the shortening of concrete that minimize the prestressing force. In this section, all losses are calculated for both type of tendons, cantilever tendons and the continuity tendons. After that it is compared with the user selected value. The average is taken at two critical section due to maximum stress differs throughout the section. The elastic shortening is then calculated.

For friction, user need to state the wooble factor, k and the coefficient of friction after which the percentage losses of prestress will be calculate at the support. At support which have the maximum moment which is most critical and also at the last section containing prestressing cantilever tendons have the highest percentage of losses. Highest percentage of losses due to the longest length hence the most frictional force.

For the anchorage draw in calculation, the user need only to key in the amount of draw in that will occur after prestressing. The percentage of losses will be calculated automatically as can be seen in the example.

For shrinkage of concrete considered due to compressive force. The percentage of losses is directly calculated while for the relaxation loss, user needed to insert the value of relaxation loss at a thousand after which the percentage of prestress loss is calculated. Finally, creep of concrete, the user only need to insert the creep coefficient to able the program to calculate the losses incurred after which the total of the long term and short term losses are added and compared with value assume earlier. If the value calculated is less than what user assume earlier then "OK!" will show if not, it will show "REDESIGN!".

| | SHORT TERM LOSSES : CANTILEVER | Prepared by<br>Checked by<br>Date | |
|---|---|---|---|
| **Ref** | **Calculation** | | **Output** |
| | **Losses in Prestress ( Cantilever tendons)** | | |
| | **Elastic Shortening** | | |
| | $\Delta\sigma_{p,el} = m\sigma_{co}$ | | |
| | $E_s$ = 195 GPa | | |
| | $E_c$ = 37 GPa | | |
| | m = 5.27 | | |
| | **At pier** | | |
| | $M_i$ = 275.305 $x10^3$kNm | | |
| | Pi = 150 $x10^3$kN | | |
| | $e$ = 2.90 m | | |
| | Area = 11.70 $m^2$ | | |
| | $A_{ps}$ = 112994 $mm^2$ | | |
| | $\sigma_{p,max} = P_i/A_{ps}$ = 1327.5 $N/mm^2$ | | |
| | Moment of Inertia, $I$ = 118.59 $m^4$ | | |
| | Radius of gyration = $(I/A)^{1/2}$ = 3.18 mm | | |
| | $\sigma_{co}$ = 14.73 $N/mm^2$ | | |
| 5.10.5.2 | **Friction** | | |
| | Prestress is applied at left hand end | | |
| | $P(x) = P_i e^{-\mu(x/r+kx)}$ | | |
| | Pretressed loss due to friction = $\Delta P_\mu(x) = P_i - P(x)$ | | |
| Tabke 5.1 | μ = 0.19 | | |
| 5.10.5.2(3) | k = 0.005 per metre | | |
| | σp,max = 1327.5 $N/mm^2$ | | |
| | δ = Ys-Yms = 0.00 m | | |
| | e at Pier = 2.90 m | | |
| | e at section const = 2.90 m | | |
| | Pi = 150 $x10^3$kN | | |
| | Pi @ Last section = 142.7 $x10^3$kN | | |
| | **At pier** | | |
| | $x$ = 0 m | | |
| | ***P(x)*** = 143 $x10^3$kN | | |
| | $\Delta P\mu(x)$ = 4.84 % | | |
| | **At secion construction of prestressing steel** | | |
| | $x$ = 52.3 m | | |
| | ***P(x)*** = 143 $x10^3$kN | | |
| | $\Delta P\mu(x)$ = 0.00 % | | |
| | **At section construction** | | |
| | Span = | | |
| | $M_i$ = 0 $x10^3$kNm | | |
| | Pi = 150 $x10^3$kN | | |
| | $e$ = 2.90 m | | |
| | Area = 9.06 $m^2$ | | |
| | $A_{ps}$ = 112994 $m^2$ | | |
| | $\sigma_{p,max} = P_i/A_{ps}$ = 1327.5 $N/mm^2$ | | |
| | Moment of Inertia, $I$ = 32.61 $m^4$ | | |
| | Radius of gyration = $(I/A)^{1/2}$ = 1.90 m | | |
| | $\sigma_{co}$ = 45.31 $N/mm^2$ | | |
| | Member are stressed sequentially | | |
| | Hence | | |
| | $\Delta\sigma_{p,el} = 0.5m\sigma_{co}$ | | |
| | = 79.10 $N/mm^2$ | | |
| 5.10.5.3 | **Anchorage draw in** | | |
| | Draw in for hole length prestressing | | |
| | δL = 5 mm | | |
| | **P(x=1)** = 149.9 $x10^3$kN | | |
| | ΔPμ(x) = 0.14 $x10^3$kN | | |
| | % losses of prestressed | | |
| | $\Delta P_A$ = 5.3 % | | |
| | Total Short Term losses | | |
| | At Last section = 11.24 | | |
| | At Support = 16.1 | | |
| | Average = 13.66 <α | | OK! |

Figure 11: Short Term Losses

| | LONG TERM LOSSES : CANTILEVER | Prepared by<br>Checked by<br>Date | |
|---|---|---|---|
| **Ref** | **Calculation** | | **Output** |
| | **Losses in Prestress ( Cantilever tendons)** | | |
| 3.1.4(6) | **Shrinkage Loss** | | |
| | $f_{cm}$ = 58.0 Mpa  $\alpha_{ds1}$ = 4  RH = 80.0 % | | |
| | $f_{cmo}$ = 10.0 Mpa  $\alpha_{ds2}$ = 0.12  $RH_o$ = 100 % | | |
| | $\beta_{RH}$ = 55[1-(RH/RH$_0$) = 0.756  Cement Clas= N | | |
| | Drying Shrinkage Stra | | |
| | $\varepsilon_{cd,0}$ = 0.85[ (220 + 110 x $\alpha_{ds,1}$) x exp(-$\alpha_{ds2}$ x $f_{cm}$ / $f_{cm0}$)] x | | |
| | = 0.85 x 660 x 0.499 x 0.756 x $10^{-6}$ | | |
| | = 0.0002116 | | |
| | value for $k_h$ | | |
| | $h_0$ = $2A_c/u$ = 2 x 9055.3 / 46029 = 0.39 mm | | |
| Table 3.3 | $k_h$ = 0.70 (Table 3.3) | | |
| | $\varepsilon_{cd}$ = 0.0002116 x 0.70 = 0.0001481 | | |
| | Autogenous Shrinkage, $\varepsilon_c$ | | |
| | $\varepsilon_{ca}$ = 2.5 ($f_{ck}$ - 10) x $10^{-6}$ | | |
| | = 0.000100 | | |
| | Total Shrinkage Str | | |
| | $\varepsilon_{cs}$ = 0.0001481 + 0.000100 = 0.0002481 | | |
| | $\Delta P_s$ = 3.15 $x10^3$kN | | |
| | **Relexation Loss** | | |
| | $\sigma_{pm0}$ = 1327.50 $N/mm^2$ | | |
| | μ = 0.750 | | |
| 3.3.2(7) | $P_{1000}$ = 2.5 | | |
| | t = 500000 hr | | |
| | $\frac{\Delta\sigma_{pr}}{\sigma_{pi}}$ = 0.049 | | |
| | $\Delta P_r$ = 3.37 $x10^3$kN | | |
| 3.1.4(2) | **Creep Loss :** | | |
| Figure 3.1 | φ(oo,t$_0$) = 1.8 | | |
| | At end segments | | |
| | $P_{mo}$ = 133 $x10^3$kN | | |
| | $\sigma_{c,QP}$ = 14.7 Mpa | | |
| | (1+AcZcp2/Ic) = 5.25 | | |
| | $\Delta P_c$ = 9.08 $x10^3$kN | | |
| | At Midspan | | |
| | $P_{mo}$ = 126 $x10^3$kN | | |
| | $\sigma_{c,QP}$ = 13.9 Mpa | | |
| | (1+AcZcp2/Ic) = 5.25 | | |
| | $\Delta P_c$ = 8.59 $x10^3$kN | | |
| | Total Percentage of long term Loss 10.1 % | | |
| | Total Losses = 23.7 % <β | | OK ! |

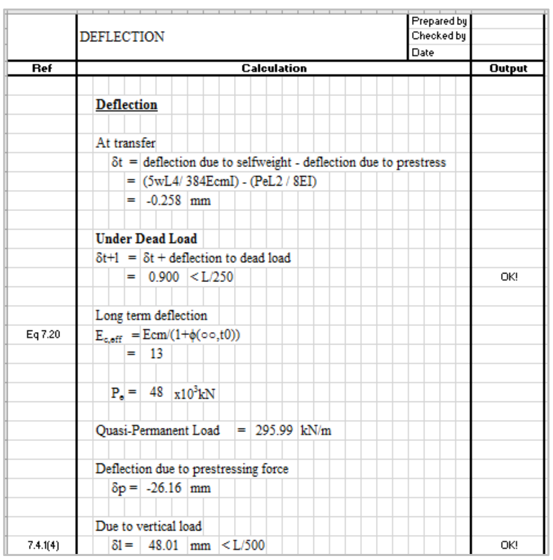
Figure 12: Long Term Losses

***Deflection***

Deflection is calculated at multiple times to account for the different stage of construction. The first at transfer deflection happened due to self-weight of box-girder and prestressing force. Next, deflection due to under permanent action is check. In the spreadsheet will show “OK!” when the value within the permitted and “REDESIGN!” will be shown after which the long term deflection will be determined. Long term deflection is calculated based on quasi-permanent loads, due to prestressing force and vertical load. The result again shall be check to make sure that it does not exceed the maximum permissible value.

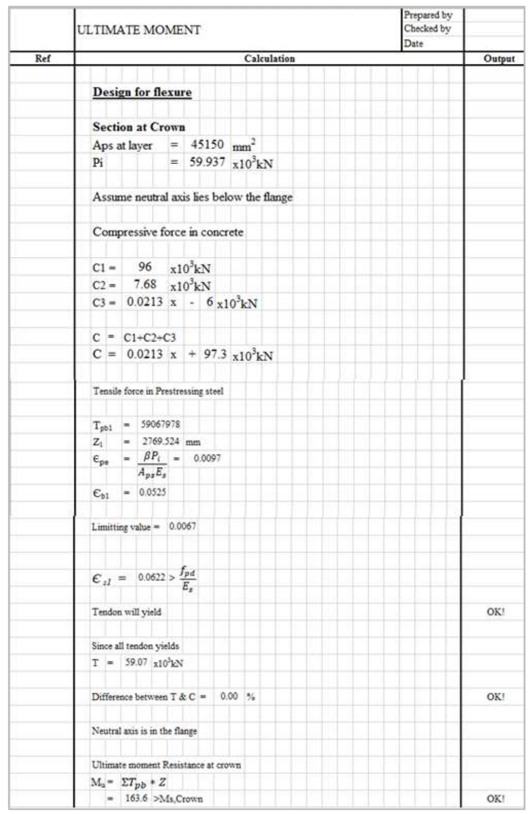
***Ultimate Moment***

To ensure the prestressed bridge to fail gradually for safety purpose of the user and also to detect any issues earlier so that they may be fixed. It is can be check by calculate the moment capacity of the structure is calculated at Ultimate and the maximum moment in the structure need to be lesser than the ultimate moment.



| | DEFLECTION | Prepared by / Checked by / Date |
|---|---|---|
| **Ref** | **Calculation** | **Output** |
| | **Deflection** | |
| | At transfer | |
| | δt = deflection due to selfweight - deflection due to prestress | |
| | = (5wL4/ 384EcmI) - (PeL2 / 8EI) | |
| | = -0.258 mm | |
| | **Under Dead Load** | |
| | δt+1 = δt + deflection to dead load | |
| | = 0.900 < L/250 | OK! |
| | Long term deflection | |
| Eq 7.20 | $E_{c,eff}$ = Ecm/(1+ϕ(∞,t0)) | |
| | = 13 | |
| | $P_e$ = 48 x10³kN | |
| | Quasi-Permanent Load = 295.99 kN/m | |
| | Deflection due to prestressing force | |
| | δp = -26.16 mm | |
| | Due to vertical load | |
| 7.4.1(4) | δl = 48.01 mm < L/500 | OK! |

Figure 13: Deflection



| | ULTIMATE MOMENT | Prepared by / Checked by / Date |
|---|---|---|
| **Ref** | **Calculation** | **Output** |
| | **Design for flexure** | |
| | **Section at Crown** | |
| | Aps at layer = 45150 mm² | |
| | Pi = 59.937 x10³kN | |
| | Assume neutral axis lies below the flange | |
| | Compressive force in concrete | |
| | C1 = 96 x10³kN | |
| | C2 = 7.68 x10³kN | |
| | C3 = 0.0213 x - 6 x10³kN | |
| | C = C1+C2+C3 | |
| | C = 0.0213 x + 97.3 x10³kN | |
| | Tensile force in Prestressing steel | |
| | $T_{pb1}$ = 59067978 | |
| | $Z_1$ = 2769.524 mm | |
| | $\epsilon_{pe} = \frac{\beta P_i}{A_{ps}E_s}$ = 0.0097 | |
| | $\epsilon_{b1}$ = 0.0525 | |
| | Limitting value = 0.0067 | |
| | $\epsilon_{s1} = 0.0622 > \frac{f_{pd}}{E_s}$ | |
| | Tendon will yield | OK! |
| | Since all tendon yields | |
| | T = 59.07 x10³kN | |
| | Difference between T & C = 0.00 % | OK! |
| | Neutral axis is in the flange | |
| | Ultimate moment Resistance at crown | |
| | $M_u = \Sigma T_{pb} * Z$ | |
| | = 163.6 >Ms,Crown | OK! |

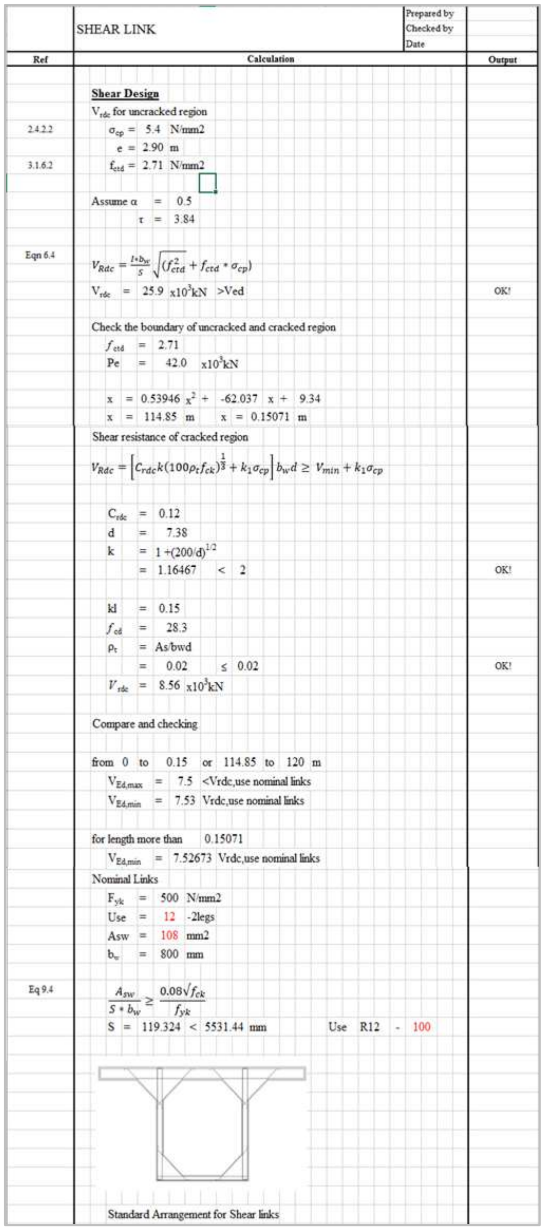
Figure 14: Ultimate Moment

***Shear Links***

To ensure the section will able to withstand the ultimate shear force, the design for shear reinforcements or shear links are calculate in this programs. In this section, the user only need to insert the size and its reinforcement area to determine the spacing needed.

***Cable Design Output***

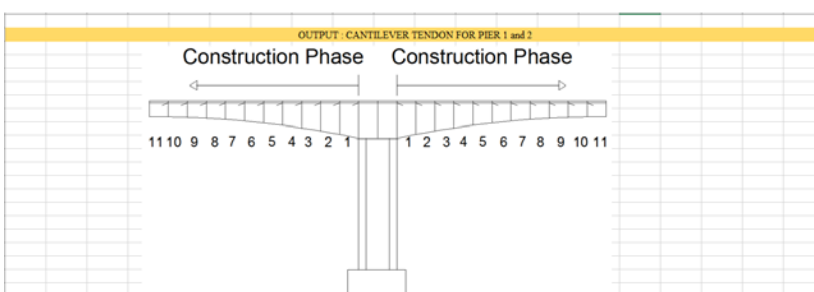
For the last section, the output of the program shown in this spreadsheet. This section most important output where the cable profile based on eccentricity is shown. Due to the nature of the section size and the method of construction. Due to reduction in moment throughout the member as a result can be shown by decreasing gradually the number of tendons per segment. In this spreadsheet contain the detail of each span and pier that has been design earlier.



| Ref | SHEAR LINK | Prepared by / Checked by / Date |
| --- | --- | --- |

| Ref | Calculation | Output |
| --- | --- | --- |
| | **Shear Design** | |
| | $V_{rdc}$ for uncracked region | |
| 2.4.2.2 | $\sigma_{cp}$ = 5.4 N/mm2 | |
| | e = 2.90 m | |
| 3.1.6.2 | $f_{ctd}$ = 2.71 N/mm2 | |
| | Assume α = 0.5 | |
| | τ = 3.84 | |
| Eqn 6.4 | $V_{Rdc} = \frac{I * b_w}{S}\sqrt{(f_{ctd}^2 + f_{ctd} * \sigma_{cp})}$ | |
| | $V_{rdc}$ = 25.9 $x10^3$kN >Ved | OK! |
| | Check the boundary of uncracked and cracked region | |
| | $f_{ctd}$ = 2.71 | |
| | Pe = 42.0 $x10^3$kN | |
| | x = 0.53946 $x^2$ + -62.037 x + 9.34 | |
| | x = 114.85 m x = 0.15071 m | |
| | Shear resistance of cracked region | |
| | $V_{Rdc} = \left[C_{rdc}k(100\rho_l f_{ck})^{\frac{1}{3}} + k_1\sigma_{cp}\right]b_w d \geq V_{min} + k_1\sigma_{cp}$ | |
| | $C_{rdc}$ = 0.12 | |
| | d = 7.38 | |
| | k = 1 +(200/d)$^{1/2}$ | |
| | = 1.16467 < 2 | OK! |
| | kl = 0.15 | |
| | $f_{cd}$ = 28.3 | |
| | $\rho_l$ = As/bwd | |
| | = 0.02 ≤ 0.02 | OK! |
| | $V_{rdc}$ = 8.56 $x10^3$kN | |
| | Compare and checking | |
| | from 0 to 0.15 or 114.85 to 120 m | |
| | $V_{Ed,max}$ = 7.5 <Vrdc,use nominal links | |
| | $V_{Ed,min}$ = 7.53 Vrdc,use nominal links | |
| | for length more than 0.15071 | |
| | $V_{Ed,min}$ = 7.52673 Vrdc,use nominal links | |
| | Nominal Links | |
| | $F_{yk}$ = 500 N/mm2 | |
| | Use = 12 -2legs | |
| | Asw = 108 mm2 | |
| | $b_w$ = 800 mm | |
| Eq 9.4 | $\frac{A_{sw}}{S * b_w} \geq \frac{0.08\sqrt{f_{ck}}}{f_{yk}}$ | |
| | S = 119.324 < 5531.44 mm Use R12 - 100 | |
| | Standard Arrangement for Shear links | |

Figure 15: Shear Links




| Seg no | Pier | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 0 | 0 |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| x(m) | | 5.23 | 10.45 | 15.68 | 20.91 | 26.14 | 31.36 | 36.59 | 41.82 | 47.05 | 0.00 | 0.00 |
| D(m) | 8.30 | 6.66 | 5.96 | 5.34 | 4.81 | 4.36 | 3.99 | 3.70 | 3.49 | 3.37 | 0.00 | 0.00 |
| Pi $x10^3$kN | 19.91 | 19.12 | 19.1 | 18.9 | 15.5 | 15.5 | 15.5 | 14.9 | 14.9 | 7.77 | 0.00 | 0.00 |
| e(m) | 3.49 | 2.67 | 2.67 | 2.34 | 2.04 | 1.78 | 1.6 | 1.4 | 1.3 | 1.16 | 0 | 0 |
| nos | 100 | 96 | 96 | 95 | 78 | 78 | 78 | 75 | 75 | 39 | 0 | 0 |

Figure 16: Output for Cantilever Tendon

### *Designer's Guide*

Based on calculation made using the "Balca Bridge 2.0", the following properties are calculated and compiled for ease of design for the engineers that use this software:

1. For cantilever tendon design, user need to start design by selecting high moment during construction to get maximum prestressing force and maximum number of tendons during construction.
2. Recommended to place a large number of tendons at beginning of construction phase.
3. If shear resistance is below the required limit, user can increase web thickness of the box girder can increase shear resistance.
4. The higher the loading apply on the bridge, the higher the depth of the bridge at the crown needs to be for the same cross section
5. Load model 1 or Gr1a is recommended in design the bridge. Load model 3 or Gr5 is highly not recommended unless the bridge is being designed specifically for special vehicle as it will greatly increase the bridge loading.
6. Amount tendons and number of segment needed during construction can be decrease by shorten the span of the bridge.
7. Tendons arrangement in one horizontal straight line. Less tendons will increase the amount of strands inside each particular tendon which depending on the engineer and supply available might be beneficial.
8. If section is deemed to be inadequate, Increase the depth of the section as the depth greatly affects the section modulus. A single meter can increase the section modulus by up to 25%

## Discussion and Verification of Spreadsheet

### *Verification of spreadsheet*

The result of the design part in the spreadsheet are verified by redesign establish box girder bridge using cantilever method. The box girder dimension, number of segment, loading during construction and loading during service need to be assume and simplified by referring establish drawing layout for box-girder dimension and use typical load value.

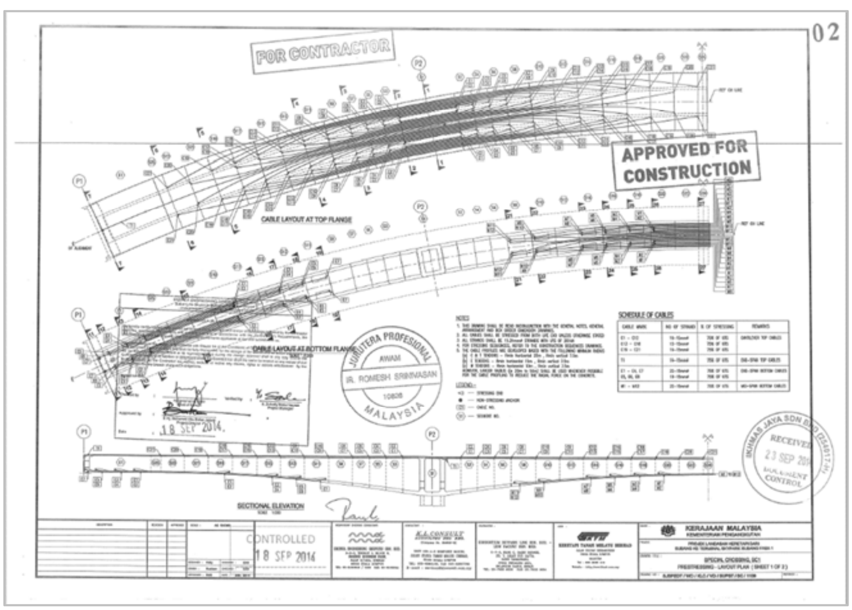



Figure 17: Establish construction Drawing

Total number of tendons use in establish cantilever bridge cable are 750 nos which equal to 150 x103kN. By comparing range of Prestressing force in spreadsheet, the Prestressing force apply in establish cantilever bridge within the range. Total number of tendons that apply to whole bridge are based on maximum moment during construction.

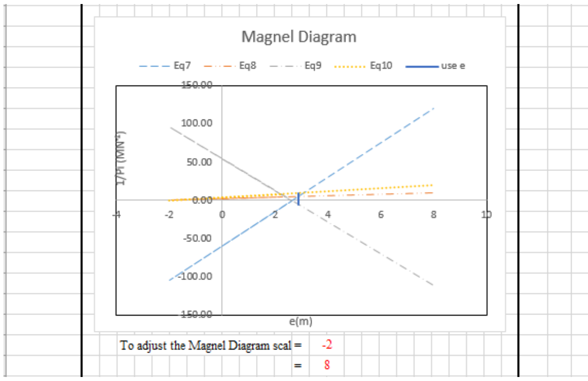



Figure 18: Magnel Diagram

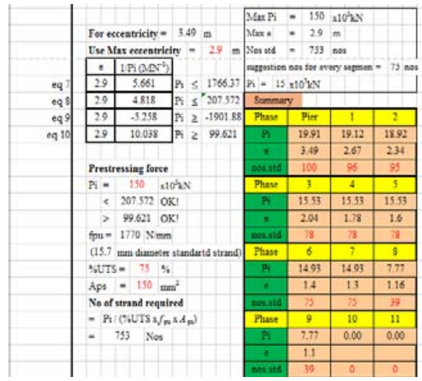



Figure 19: Pi Checking

In magnel diagram show that by using 2.9 m as maximum eccentiricity, the prestressing force range are 207.572 $x10^3$kN < Pi < 99.621 $x10^3$kN. This shows that prestressing force in establish construction significant with prestressing force range from the spreadsheet.

***Limitation***

The limitation in the program are:

1. Length of every segment had specified into equal length.
2. Number of segment limited to three, five, seven, nine and eleven number of segment.
3. Tendon arrangement only consider as one-layer cable arrangement

***Recommendation***

There are several areas that can be improve that can be done got this computer program more applicable design.

1. Provide various type of section that can be design such as trapezoidal box-girders. It is can be done by using polar coordinate method
2. Use different form of software to develop the software such as MatLab which can overcome the limitation that are faced when using Microsoft Excel.
3. Include the design procedures for external prestressing so that users have a wider range of choices
4. Implement more parameter in consideration in process designing the bridge such as loading that more specified during construction work, external load such as wind load and other related load need to consider.
5. Develop an external analysis program using finite element method which can over the limitations imposed by moment distribution method which is not the best method to calculate sections of differing sizes and loading.

**Conclusion**

The spreadsheet is able to design the cantilever cable and continuity cable under loading consider during construction of cantilever bridge and during service. Eurocode can be applied easily by using this spreadsheet which contribute to the design of Cable design based on factors of safety, serviceability, economy and elegance. The spreadsheet also contributes to the performance in terms of suitability and reliability design in the real situation based on construction method. User friendly, time saving and ease to use for the beginners would be benefits of this program. Although there is some difference of results design by program and establish result due to several loading not consider during design but certainly the program can perform well and provide reliable results in the end of the process to ensure the safety, serviceability, reliability and optimum tendon design and arrangement of the tendons of the cantilever bridge that related to the real situation of construction site.

## References


[1] Benaim, R. (2008). The Design of Prestressed Concrete Bridges, Concepts and Principle. Abingdon: Taylor & Francis

[2] J.-A. Calgaro, M. T. (2010). DESIGNERS' GUIDE TO EUROCODE 1: ACTION ON BRIDGES. London: Thomas Telford Limited

[3] KRISTEK, V. (1979). Theory of Box Girders. Chichester: JOHN WILEY & SONS.

[4] Menn, C. (1990). Prestressed Concrete Bridges. Basel: Birkhauser Verlag.

[5] Setra. (2007, September). Design Guide – Prestressed concrete bridges built using the cantilever method.

[6] Jacques Mathivat (1983), The Cantilever Construction of Prestressed Concrete Bridges.JOHN WILEY & SONS.

[7] Benyamin (2015), Computerised Design of Box-Girder Bridge Using Balanced Cantilever Method (Final Year Project). University Teknologi Malaysia,Skudai.

[8] Honório.J.D (2007), Conceptual Design of Long-Span Cantilever Constructed Concrete bridges (Master thesis). Structural Design & Bridges.