TERM PROJECT FOR STRUCTURAL ANALYSIS 2 – CIV519

Part a, Introduction:

This entry is about an individually done term project of a 4th year technical elective course called structural analysis 2. The project required us to make a detailed analysis of a research paper related with course material, mainly the steel trusses. The main goal of this project was to practice the course material and learn about the trusses that are used in real life. Another important goal of it was to improve our ability on analysing a published report. The project also indirectly aimed at the usage of computer software for solving complex structural loading systems that will take long time to solve by hand. The paper this project was about is linked at the part b of this entry.

The paper was talking about an analysis method called the two-stage method. The method was proposed by Janusz Rebielak, a Polish professor at the department of architecture in Cracow University of Technology. The method was inspired from the buckling analogy of steel under compression. His method was based on the principle of superposition and it was for approximately solving appropriate statically indeterminate plane trusses.

I broke the analysis in four parts mainly focusing on historic and current bridges since steel trusses like mentioned in the report are encountered mostly on bridge designs. In the first part, I repeated the examples shown in the paper using mostly RISA-3D and compared my results with the results of the paper. In the second part, I examined the applicability of the proposed two-stage method to 4 widely used truss types. In the third part, I commented and discussed on possible limitations of the proposed method and in the final part I gave my opinion about the method proposed as well as pointed out some possible mistakes.

I found this project to be particularly helpful in improving my discussion, interpretation of data and commenting skills. I also practiced my ability to use a commercial design and analysis software and learned new functions of it. I believed in the usefulness of this project and spent considerable time and effort on this project since as a future structural engineer, I know that reading and analysing reports will be a substantial part of my work.

Part b, the paper:

The paper is called "New Simple Method of Calculation of Statically Indeterminate Trusses" and can be found online at: <u>http://www.sci-en-tech.com/apcom2013/APCOM2013-Proceedings/PDF_FullPaper/1594_J_Rebielak.pdf</u>. The original version can also be found in UofT's engineering library. It was also published in 2014 in the Journal of Mathematics and System Science 4 (p367-371).

Part c, the repeated examples from the paper, results and my commentary:

Below are my analysis results for the first example studied at the paper:









| Member | Axial Forces From | Axial Forces From | Sum of Axial | Axial Forces From | Absolute Difference | Percent Error | SAFER or |
|--------|---------------------|----------------------|------------------|-------------------|----------------------|----------------|----------|
| Label | First Stage (kN)(1) | Second Stage (kN)(2) | Forces (1+2)(kN) | Software (kN) | of Axial Forces (kN) | Per Member (%) | NOT |
| M1 | 0 | -2 | -2 | -1.905 | 0.095 | 4.99 | SAFER |
| M2 | 0 | -3 | -3 | -2.915 | 0.085 | 2.92 | SAFER |
| M3 | 0 | -3 | -3 | -2.915 | 0.085 | 2.92 | SAFER |
| M4 | 0 | -2 | -2 | -1.905 | 0.095 | 4.99 | SAFER |
| M5 | 0.75 | -1.25 | -0.5 | -0.405 | 0.095 | 23.46 | SAFER |
| M6 | 2.25 | -2.75 | -0.5 | -0.32 | 0.18 | 56.25 | SAFER |
| M7 | 2.75 | -3.25 | -0.5 | -0.33 | 0.17 | 51.52 | SAFER |
| M8 | 2.25 | -2.75 | -0.5 | -0.32 | 0.18 | 56.25 | SAFER |
| M9 | 0.75 | -1.25 | -0.5 | -0.405 | 0.095 | 23.46 | SAFER |
| M10 | 2 | 0 | 2 | 2.095 | 0.095 | 4.53 | N. SAFE |
| M11 | 3 | 0 | 3 | 3.085 | 0.085 | 2.76 | N. SAFE |
| M12 | 3 | 0 | 3 | 3.085 | 0.085 | 2.76 | N. SAFE |
| M13 | 2 | 0 | 2 | 2.095 | 0.095 | 4.53 | N. SAFE |
| M14 | -0.884 | -0.884 | -1.768 | -1.768 | 0 | 0.00 | EQUAL |
| M15 | 0.884 | 0.884 | 1.768 | 1.768 | 0 | 0.00 | EQUAL |
| M16 | -0.884 | 1.945 | 1.061 | 0.927 | 0.134 | 14.46 | SAFER |
| M17 | -0.884 | 1.945 | 1.061 | 0.927 | 0.134 | 14.46 | SAFER |
| M18 | -1.945 | 0.884 | -1.061 | -1.195 | 0.134 | 11.21 | N. SAFE |
| M19 | -1.945 | 0.884 | -1.061 | -1.195 | 0.134 | 11.21 | N. SAFE |
| M20 | -1.945 | 2.298 | 0.353 | 0.233 | 0.12 | 51.50 | SAFER |
| M21 | -1.945 | 2.298 | 0.353 | 0.233 | 0.12 | 51.50 | SAFER |
| M22 | -2.298 | 1.945 | -0.353 | -0.474 | 0.121 | 25.53 | N. SAFE |
| M23 | -2.298 | 1.945 | -0.353 | -0.474 | 0.121 | 25.53 | N. SAFE |
| M24 | -2.298 | 1.945 | -0.353 | -0.474 | 0.121 | 25.53 | N. SAFE |
| M25 | -2.298 | 1.945 | -0.353 | -0.474 | 0.121 | 25.53 | N. SAFE |
| M26 | -1.945 | 2.298 | 0.353 | 0.233 | 0.12 | 51.50 | SAFER |
| M27 | -1.945 | 2.298 | 0.353 | 0.233 | 0.12 | 51.50 | SAFER |
| M28 | -1.945 | 0.884 | -1.061 | -1.195 | 0.134 | 11.21 | N. SAFE |
| M29 | -1.945 | 0.884 | -1.061 | -1.195 | 0.134 | 11.21 | N. SAFE |
| M30 | -0.884 | 1.945 | 1.061 | 0.927 | 0.134 | 14.46 | SAFER |
| M31 | -0.884 | 1.945 | 1.061 | 0.927 | 0.134 | 14.46 | SAFER |
| M32 | -0.884 | -0.884 | -1.768 | -1.768 | 0 | 0.00 | EQUAL |
| M33 | 0.884 | 0.884 | 1.768 | 1.768 | 0 | 0.00 | EQUAL |

At the left, there is a spreadsheet which shows the numerical results. All the approximations that go on the safer side is not a big issue other than economic disadvantage if the load applied is high. I'm focusing on the not safe values. Most of the not safe forces have a low percentage error and this error can be compensated by safety factors used in design. But if I focus on members 22, 23, 24 and 25. I see an error of 25.53%. But these members are the ones

with the smallest force value. So here again the minimum requirements of the design code used will govern. Therefore, this "specific" structure can be designed by two-stage method although I don't recommend this in 2018. But can it be done? Yes.

After solving example 1, I noticed that for most of the time I get the same results. My results for example 1 at the paper differ at some points. Those can be seen below. Green circles represent not very important mismatches. Green circles with a red star mark are significant mismatches. In this example, all the only green mismatches are due to roundoff which is not very significant. Mismatch number 5, 6, 7, 8 and 15, 16, 21, 22 is because of a calculation error or too much rounding from authors part while doing the calculations. Because of this difference, significant mismatches 29, 30, 31, 32, 33, 34, 35, 36 happen. Mismatch 25 and 26 are the most significant for this example and I think the author or the editor copied the shape from above and forgot to change those values.



Figure 3. Arrangement of force values calculated in the first stage



Figure 4. Arrangement of force values calculated in the second stage



Figure 5. Values of forces obtained as a result of appropriate application of principle of superposition in the proposed two-stage method of calculation

Example 2:

Below are my analysis results for the second example studied at the paper.













| Member | Axial Forces From | Axial Forces From | Sum of Axial | Axial Forces From | Absolute Difference | Percent Error | SAFER OR |
|--------|---------------------|----------------------|------------------|-------------------|----------------------|----------------|----------|
| Label | First Stage (kN)(1) | Second Stage (kN)(2) | Forces (1+2)(kN) | Software (kN) | of Axial Forces (kN) | Per Member (%) | NOT |
| M1 | 0 | 0.5 | 0.5 | 0.595 | 0.095 | 15.97 | N. SAFE |
| M2 | 0 | -4 | -4 | -3.915 | 0.085 | 2.17 | SAFER |
| M3 | 0 | -7.5 | -7.5 | -7.414 | 0.086 | 1.16 | SAFER |
| N/4 | 0 | -10 | -10 | -9.914 | 0.086 | 0.87 | SAFER |
| M6 | 0 | -11.5 | -11.3 | -11.414 | 0.086 | 0.73 | SAFER |
| M7 | 0 | -11.5 | -11.5 | -11.414 | 0.086 | 0.75 | SAFER |
| M8 | 0 | -10 | -10 | -9.914 | 0.086 | 0.87 | SAFER |
| M9 | 0 | -7.5 | -7.5 | -7.414 | 0.086 | 1.16 | SAFER |
| M10 | 0 | -4 | -4 | -3.915 | 0.085 | 2.17 | SAFER |
| M11 | 0 | 0.5 | 0.5 | 0.595 | 0.095 | 15.97 | N. SAFE |
| M12 | -0.5 | 0 | -0.5 | -0.405 | 0.095 | 23.46 | SAFER |
| M13 | 1.5 | -2 | -0.5 | -0.32 | 0.18 | 56.25 | SAFER |
| M15 | 3.5 | -0- | -0.3 | -0.329 | 0.171 | 51.96 | SAFER |
| M16 | 10.5 | -11 | -0.5 | -0.328 | 0.172 | 52.44 | SAFER |
| M17 | 11.5 | -12 | -0.5 | -0.328 | 0.172 | 52.44 | SAFER |
| M18 | 11.5 | -12 | -0.5 | -0.328 | 0.172 | 52.44 | SAFER |
| M19 | 10.5 | -11 | -0.5 | -0.328 | 0.172 | 52.44 | SAFER |
| M20 | 8.5 | -9 | -0.5 | -0.328 | 0.172 | 52.44 | SAFER |
| M21 | 5.5 | -6 | -0.5 | -0.329 | 0.171 | 51.98 | SAFER |
| M22 | 1.5 | -2 | -0.5 | -0.32 | 0.18 | 56.25 | SAFER |
| N123 | -0.5 | 0 | -0.5 | -0.405 | 0.095 | 23.40 | SAFER |
| M25 | -0.5 | 0 | -0.5 | 4.085 | 0.085 | 2 08 | N SAFE |
| M26 | 7.5 | 0 | 7.5 | 7.586 | 0.086 | 1.13 | N. SAFE |
| M27 | 10 | 0 | 10 | 10.086 | 0.086 | 0.85 | N. SAFE |
| M28 | 11.5 | 0 | 11.5 | 11.586 | 0.086 | 0.74 | N. SAFE |
| M29 | 12 | 0 | 12 | 12.086 | 0.086 | 0.71 | N. SAFE |
| M30 | 11.5 | 0 | 11.5 | 11.586 | 0.086 | 0.74 | N. SAFE |
| M31 | 10 | 0 | 10 | 10.086 | 0.086 | 0.85 | N. SAFE |
| N132 | 7.5 | 0 | 7.5 | /.586 | 0.086 | 1.13 | N. SAFE |
| M34 | -0.5 | 0 | -0.5 | -0.405 | 0.085 | 23.46 | SAFER |
| M35 | 0 | -0.707 | -0.707 | -0.841 | 0.134 | 15.93 | N. SAFE |
| M36 | 2.121 | 1.414 | 3.535 | 3.402 | 0.133 | 3.91 | SAFER |
| M37 | 0.707 | 0 | 0.707 | 0.573 | 0.134 | 23.39 | SAFER |
| M38 | -1.414 | -2.121 | -3.535 | -3.67 | 0.135 | 3.68 | N. SAFE |
| M39 | -1.414 | 4.243 | 2.829 | 2.708 | 0.121 | 4.47 | SAFER |
| M40 | -1.414 | 4.243 | 2.829 | 2.708 | 0.121 | 4.47 | SAFER |
| N/41 | -4.243 | 1.414 | -2.829 | -2.948 | 0.119 | 4.04 | N. SAFE |
| M42 | -4.243 | 6 364 | -2.829 | -2.948 | 0.119 | 4.04 | SAFER |
| M44 | -4.243 | 6.364 | 2.121 | 2 | 0.121 | 6.05 | SAFER |
| M45 | -6.364 | 4.243 | -2.121 | -2.243 | 0.122 | 5.44 | N. SAFE |
| M46 | -6.364 | 4.243 | -2.121 | -2.243 | 0.122 | 5.44 | N. SAFE |
| M47 | -6.364 | 7.778 | 1.414 | 1.293 | 0.121 | 9.36 | SAFER |
| M48 | -6.364 | 7.778 | 1.414 | 1.293 | 0.121 | 9.36 | SAFER |
| M49 | -7.778 | 6.364 | -1.414 | -1.536 | 0.122 | 7.94 | N. SAFE |
| M51 | -7.778 | 0.304 | -1.414 | -1.530 | 0.122 | 7.94 | N. SAFE |
| M52 | -7.778 | 8.485 | 0.707 | 0.586 | 0.121 | 20.65 | SAFER |
| M53 | -8.485 | 7.778 | -0.707 | -0.828 | 0.121 | 14.61 | N. SAFE |
| M54 | -8.485 | 7.778 | -0.707 | -0.828 | 0.121 | 14.61 | N. SAFE |
| M55 | -8.485 | 8.485 | 0 | -0.121 | 0.121 | 100.00 | N. SAFE |
| M56 | -8.485 | 8.485 | 0 | -0.121 | 0.121 | 100.00 | N. SAFE |
| M57 | -8.485 | 8.485 | 0 | -0.121 | 0.121 | 100.00 | N. SAFE |
| N150 | -8.485 | 8.485 | 0 707 | -0.121 | 0.121 | 100.00 | N. SAFE |
| M60 | -8.485 | 7.778 | -0.707 | -0.828 | 0.121 | 14.61 | N SAFE |
| M61 | -7.778 | 8.485 | 0.707 | 0.586 | 0.121 | 20.65 | SAFER |
| M62 | -7.778 | 8.485 | 0.707 | 0.586 | 0.121 | 20.65 | SAFER |
| M63 | -7.778 | 6.364 | -1.414 | -1.536 | 0.122 | 7.94 | N. SAFE |
| M64 | -7.778 | 6.364 | -1.414 | -1.536 | 0.122 | 7.94 | N. SAFE |
| M65 | -6.364 | 7.778 | 1.414 | 1.293 | 0.121 | 9.36 | SAFER |
| M66 | -6.364 | 7.778 | 1.414 | 1.293 | 0.121 | 9.36 | SAFER |
| M68 | -6.364 | 4.243 | -2.121 | -2.243 | 0.122 | 5.44 | N SAFE |
| M69 | -0.364 | 4.243 | -2.121 2.121 | -2.243 | 0.122 | 5.44 6.05 | SAFER |
| M70 | -4.243 | 6.364 | 2.121 | 2 | 0.121 | 6.05 | SAFER |
| M71 | -4.243 | 1.414 | -2.829 | -2.948 | 0.119 | 4.04 | N. SAFE |
| M72 | -4.243 | 1.414 | -2.829 | -2.948 | 0.119 | 4.04 | N. SAFE |
| M73 | -1.414 | 4.243 | 2.829 | 2.708 | 0.121 | 4.47 | SAFER |
| M74 | -1.414 | 4.243 | 2.829 | 2.708 | 0.121 | 4.47 | SAFER |
| M75 | -1.414 | -2.121 | -3.535 | -3.67 | 0.135 | 3.68 | N. SAFE |
| M77 | 0.707 | 0 | 0./0/ | 0.573 | 0.134 | 23.39 | SAFER |
| M78 | 2.121 | -0.707 | -0.707 | -0.841 | 0.133 | 15.93 | N. SAFE |
| | 0 | | | 0.014 | 0.101 | | |

At the left, there is a spreadsheet which shows numerical results. All the approximations that go on the safer side is not a big issue other than economic disadvantage if the load applied is high. I'm focusing on the not safe values. When I look at the spreadsheet overall, I see two type of not safes. The first type is where the force value is small considered to other members, but the percent difference is big, and the second type is where the relative difference of forces is small in percentage. The small relative difference is usually not an issue since everything we design for has a safety factor. In this case, the other one is also not an issue. As an example, I can give member 55. At that member, the force is approximated as 0 but in reality, it is 0.121 kN compression. 0.121 is a small value and most likely minimum requirements by the building code will govern at this member, even the applied load gets scaled x100. So, I think this is not an issue. This "specific" structure can be approximated by two-stage method although I don't recommend this in 2018. But can it be done? Yes.

Similar to example 1, after solving example 2, I noticed that for most of the time I get the same results. My results for example 2 at the paper differ at some points. Those can be seen below. Green circles represent not very important mismatches. Green circles with a red star mark are important mismatches. Green mismatch 1 is a typo from the authors part and all the other green mismatches are due to roundoff which is not very significant. Mismatch number 2 and 5 with a red mark is a sign error from authors part. The sign signifies compression or tension, so it can be considered important. But in reality, I think when he was adding the forces, he made a mistake. Nevertheless, I believe he or his assistants were supposed to check it before publishing a report. There might be a publishing mistake as well.



Figure 7. Values of forces obtained in the first stage of the proposed method of calculation



Figure 9. Final values of forces obtained a) in the proposed two-stage method of calculations, b) by application of the computer software ICES-STRUDL

BAILEY TRUSS

Bailey truss was invented by Donald Bailey in 20th century. At that time, there was a war and soldiers had to carry the bridge panels and assemble them on site. The bailey panel has certain specific dimensions according to the field manual but for the purposes of this project, I will stick with the dimensioning used in the report.

The original Bailey panel looked like this:



These panels were to be assembled by soldiers quickly to form the bridge. According to the field construction manual, the diamond braces are suggested to be welded although a pin connection is also allowable, top and bottom chord is continuous but pinned between panels.

However, in modern bridges, longer panels can be constructed. So, for modeling purposes, the top and bottom chord of the bridge can be modeled continuous.

In fact, this type of bridge configuration will only have axial forces given that all the loads are applied to the joints vertically.

Simple trusses mentioned in the report have all members with both ends released. This type truss modeling works for only certain types of trusses. In reality, some or sometimes all members can be fixed and still the structure can be considered a truss due to the way it is loaded or designed.

The Bailey truss can be modeled in several ways which all gives the same result. However, Bailey truss cannot be modeled having all members released. If the equation given in the report to be used one can find that the truss modeled that way will be statically unstable to the 1st degree. Modern finite element solver found in computer software will give a warning and verify that as well.

Hand Calculation of Degree of Static Stability Ds:

Software Solver warning for instability:

Unstable Model Ditrus = M - (2.j-r) (Same Equation found in the reports Instabilities were detected and locked for this model different losbelling) For a list of the instabilities, review the Reactions results. All locked joints will display the message "LOCKED" for the reactio For Bailey Truss there are corresponding to the direction the joint was locked. 62 Members $D_{strus} =$ 3 Reactions 62 - (2.33 - 3) = -133 Jaints Would you like to create a new model view with only the locked joints selected? Help Yes No

For hybrid frame-truss structures, another formula can be used to analyse the degree of static indeterminacy. The truss equation used in the report is a sub-equation of this general equation:



References for the equation:

"Structural Analysis: In Theory and Practice By Alan Williams"

"Di Maggio , F. C. Statical indeterminacy and stability of structures . Proc. Am. Soc. Civil Eng.89 (ST3). June 1963. pp. 63–75"

Simplified Righton a truss Ex: For a true Ps = m - (2j-r) (r=3 usually for true a true) any EA same for all s constant Steen areas 20. s constant Tiela Stress A very large 2 INF. = 6 - (2.4-3) 4 , 1st degree in determinate $\frac{12}{12}$ No of members = 6
No of joints = 6
No of joints = 6
No of reactions = 3 = 126 degree invictemente q = (3-1) + (3-1) + (3-1) + (3-1) A = 126 degree invictemente= 8 A pin always relates all man bas contented or to it at the d=2.m-j for a trues raller connected end q=2.6-4 =8 € the A true must have all pin-pin releases for all ends for all members +7) & There are equivalent 1 = 1 / IF DS < O =+ Unstable IF DS = C =+ Determinate If DS > 0 = Indeterminate Or if 1 eigenvalue &= (-) Unstable in eigenvalue alganic analysis, (requires software [4, K big]

I modeled the Bailey truss in an appropriate configuration and run computer first order linear elastic analysis. This is just to get the axial forces. I could have fixed all ends and run an analysis as well. For this case it doesn't really matter.

I applied loads to every joint, but I also did model applying forces to joints where vertical members exist. I will present those results numerically and give graphical output for the case where loads applied to every single joint in the top chord. I wanted to include the other case as well since it is widely used.

Example of Bailey Truss where loads are applied where vertical members exist:



The results for loads applied to every single top joint:







Applicability of the two-stage method as the way it is described in the report:

Two-stage method to this truss cannot be applied, however, a modified version of it that doesn't care about the degree of static indeterminacy where all top members are removed in the first, and all bottom are removed in the second may be applied. But, since removing all the members in the top chord or bottom chord doesn't make the structure determinate, still a computer must be used. So, basically, for this truss, two-stage method is pointless.

The question asks for the applicability so here are my numerical results and my comments:

Before putting the numerical data, I want to point out that I tried some release configurations including the one presented above for software results. The best prediction of axial forces was when I fixed all the joints. So, I will just present that data. For the configuration above, two-stage like (not exactly two-stage described in the paper) method gives unacceptable results.

Member Layout Used in numerical results:



First case where loads are applied to every single top joint, Tension (+):

| Member | Axial Forces From | Axial Forces From | Sum of Axial | Axial Forces From | Absolute Difference | Percent Error | SAFER OR |
|--------|---------------------|----------------------|------------------|-------------------|----------------------|----------------|----------|
| Label | First Stage (kN)(1) | Second Stage (kN)(2) | Forces (1+2)(kN) | Software (kN) | of Axial Forces (kN) | Per Member (%) | NOT |
| M1 | 0 | 0.1905 | 0.1905 | 0 | 0.1905 | INF | SAFER |
| M2 | 0 | -4.4405 | -4.4405 | -4.5 | 0.0595 | 1.32 | N. SAFE |
| M3 | 0 | -4.2505 | -4.2505 | -4.5 | 0.2495 | 5.54 | N. SAFE |
| M4 | 0 | -6.982 | -6.982 | -8 | 1.018 | 12.73 | N. SAFE |
| M5 | 0 | -6.8865 | -6.8865 | -8 | 1.1135 | 13.92 | N. SAFE |
| M6 | 0 | -7.797 | -7.797 | -8.5 | 0.703 | 8.27 | N. SAFE |
| M7 | 0 | -7.797 | -7.797 | -8.5 | 0.703 | 8.27 | N. SAFE |
| M8 | 0 | -6.8865 | -6.8865 | -8 | 1.1135 | 13.92 | N. SAFE |
| M9 | 0 | -6.982 | -6.982 | -8 | 1.018 | 12.73 | N. SAFE |
| M10 | 0 | -4.2505 | -4.2505 | -4.5 | 0.2495 | 5.54 | N. SAFE |
| M11 | 0 | -4.4405 | -4.4405 | -4.5 | 0.0595 | 1.32 | N. SAFE |
| M12 | 0 | 0.1905 | 0.1905 | 0 | 0.1905 | INF | SAFER |
| M13 | -2.9785 | -3.25 | -6.2285 | -6.5 | 0.2715 | 4.18 | N. SAFE |
| M14 | -0.5 | -0.842 | -1.342 | -1 | 0.342 | 34.20 | SAFER |
| M15 | 1.9385 | 0 | 1.9385 | 0 | 1.9385 | INF | SAFER |
| M16 | -0.5 | -2.676 | -3.176 | -1 | 2.176 | 217.60 | SAFER |
| M17 | 3.328 | 0 | 3.328 | 0 | 3.328 | INF | SAFER |
| M18 | -0.5 | -4.053 | -4.553 | -1 | 3.553 | 355.30 | SAFER |
| M19 | 3.778 | 0 | 3.778 | 0 | 3.778 | INF | SAFER |
| M20 | -0.5 | -4.503 | -5.003 | -1 | 4.003 | 400.30 | SAFER |
| M21 | 3.328 | 0 | 3.328 | 0 | 3.328 | INF | SAFER |
| M22 | -0.5 | -4.053 | -4.553 | -1 | 3.553 | 355.30 | SAFER |
| M23 | 1.9385 | 0 | 1.9385 | 0 | 1.9385 | INF | SAFER |
| M24 | -0.5 | -2.676 | -3.176 | -1 | 2.176 | 217.60 | SAFER |
| M25 | -2.9785 | -3.25 | -6.2285 | -6.5 | 0.2715 | 4.18 | N. SAFE |
| M26 | -0.5 | -0.842 | -1.342 | -1 | 0.342 | 34.20 | SAFER |
| M27 | -0.156 | 0 | -0.156 | 0 | 0.156 | INF | SAFER |
| M28 | 4,5095 | 0 | 4,5095 | 5.5 | 0.9905 | 18.01 | N. SAFE |
| M29 | 4 3195 | 0 | 4 3195 | 5.5 | 1,1805 | 21.46 | N. SAFE |
| M30 | 7 051 | 0 | 7.051 | 8 | 0.949 | 11.86 | N. SAFE |
| M31 | 6.955 | 0 | 6.955 | 8 | 1.045 | 13.06 | N. SAFE |
| M32 | 7.866 | 0 | 7.866 | 95 | 1.634 | 17.20 | N SAFE |
| M33 | 7.866 | 0 | 7.866 | 9.5 | 1.634 | 17.20 | N. SAFE |
| M34 | 6.955 | 0 | 6.955 | 8 | 1.045 | 13.06 | N. SAFE |
| M35 | 7.051 | 0 | 7.051 | 8 | 0.949 | 11.86 | N. SAFE |
| M36 | 4 3195 | 0 | 4 3195 | 55 | 1 1805 | 21.46 | N SAFE |
| M37 | 4,5095 | 0 | 4,5095 | 5.5 | 0.9905 | 18.01 | N. SAFE |
| M38 | -0.156 | 0 | -0.156 | 0 | 0.156 | INF | SAFER |
| M39 | -1.2145 | -2.6575 | -3.872 | -3.889 | 0.017 | 0.44 | N. SAFE |
| M40 | -1.02 | 4,304 | 3,284 | 2.475 | 0.809 | 32.69 | SAFER |
| M41 | -4.4405 | 0.82 | -3.6205 | -3.889 | 0.2685 | 6.90 | N. SAFE |
| M42 | 2.529 | 1.0355 | 3,5645 | 3.889 | 0.3245 | 8.34 | N. SAFE |
| M43 | -2.5295 | 0.505 | -2.0245 | -3.182 | 1,1575 | 36.38 | N. SAFE |
| M44 | -2.3775 | 4.655 | 2.2775 | 1.768 | 0.5095 | 28.82 | SAFER |
| M45 | -4.7925 | 2,1935 | -2,599 | -1.768 | 0.831 | 47.00 | SAFER |
| M46 | -0.642 | 2.345 | 1.703 | 1.768 | 0.065 | 3.68 | N. SAFE |
| M47 | -3.155 | 2,7525 | -0.4025 | -1.061 | 0.6585 | 62.06 | N. SAFE |
| M48 | -3.105 | 4.135 | 1.03 | -0.353 | 1.383 | 391.78 | SAFER |
| M49 | -4.273 | 2,9205 | -1.3525 | -1.061 | 0.2915 | 27.47 | SAFER |
| M50 | -2.8905 | 2,9705 | 0.08 | 1.061 | 0.981 | 92.46 | N. SAFE |
| M51 | -3 105 | 4 135 | 1.03 | -1.061 | 2 091 | 197.08 | N SAFE |
| M52 | -3 155 | 2 7525 | -0 4025 | -0.353 | 0.0495 | 14.02 | SAFER |
| M53 | -2.8905 | 2,9705 | 0.08 | -1.061 | 1.141 | 107.54 | N. SAFE |
| M54 | -4 273 | 2.9705 | -1 3525 | 1.061 | 2 4135 | 227.47 | SAFER |
| M55 | -2,3775 | 4 655 | 2.2775 | -3 182 | 5 4595 | 171 57 | N. SAFE |
| M56 | -2.5795 | 0.505 | -2 0245 | 1 768 | 3 7925 | 214 51 | SAFER |
| M57 | -0 642 | 2 245 | 1 703 | -1 768 | 3.7525 | 196 32 | N. SAFE |
| M58 | -4 7925 | 2.345 | -2 500 | 1 768 | A 267 | 247 00 | SAFFR |
| M59 | -1 02 | 4 304 | 3 284 | -3 880 | 7 172 | 184 44 | N. SAFE |
| M60 | -1,2145 | -2 6575 | -3 872 | 2 475 | 6 347 | 256 44 | SAFER |
| M61 | 2 529 | 1 0355 | 3 5645 | -3 880 | 7 4535 | 191 66 | N. SAFE |
| M62 | -4,4405 | 0.82 | -3.6205 | 3.889 | 7.5095 | 193.10 | N. SAFE |
| | | 0.01 | 0.0200 | 0.000 | | | |

Second case where loads are applied to every top joint where vertical member exists, Tension (+):

| Member | Axial Forces From | Axial Forces From | Sum of Axial | Axial Forces From | Absolute Difference | Percent Error | SAFER OR |
|--------|---------------------|----------------------|------------------|-------------------|----------------------|----------------|----------|
| Label | First Stage (kN)(1) | Second Stage (kN)(2) | Forces (1+2)(kN) | Software (kN) | of Axial Forces (kN) | Per Member (%) | NOT |
| M1 | 0 | 0.087 | 0.087 | 0 | 0.087 | INF | SAFER |
| M2 | 0 | -2.237 | -2.237 | -2.5 | 0.263 | 10.52 | N. SAFE |
| M3 | 0 | -2.143 | -2.143 | -2.5 | 0.357 | 14.28 | N. SAFE |
| M4 | 0 | -3.508 | -3.508 | -4 | 0.492 | 12.30 | N. SAFE |
| M5 | 0 | -3.46 | -3.46 | -4 | 0.54 | 13.50 | N. SAFE |
| M6 | 0 | -3.916 | -3.916 | -4.5 | 0.584 | 12.98 | N. SAFE |
| M7 | 0 | -3.916 | -3.916 | -4.5 | 0.584 | 12.98 | N. SAFE |
| M8 | 0 | -3.46 | -3.46 | -4 | 0.54 | 13.50 | N. SAFE |
| M9 | 0 | -3.508 | -3.508 | -4 | 0.492 | 12.30 | N. SAFE |
| M10 | 0 | -2.143 | -2.143 | -2.5 | 0.357 | 14.28 | N. SAFE |
| M11 | 0 | -2.237 | -2.237 | -2.5 | 0.263 | 10.52 | N. SAFE |
| M12 | 0 | 0.087 | 0.087 | 0 | 0.087 | INF | SAFER |
| M13 | -1.597 | -1.75 | -3.347 | -3.5 | 0.153 | 4.37 | N. SAFE |
| M14 | -0.5 | -0.653 | -1.153 | -1 | 0.153 | 15.30 | SAFER |
| M15 | 1.029 | 0 | 1.029 | 0 | 1.029 | INF | SAFER |
| M16 | -0.5 | -1.529 | -2.029 | -1 | 1.029 | 102.90 | SAFER |
| M17 | 1.72 | 0 | 1.72 | 0 | 1.72 | INF | SAFER |
| M18 | -0.5 | -2.22 | -2.72 | -1 | 1.72 | 172.00 | SAFER |
| M19 | 1.945 | 0 | 1.945 | 0 | 1.945 | INF | SAFER |
| M20 | -0.5 | -2.445 | -2.945 | -1 | 1.945 | 194.50 | SAFER |
| M21 | 1.72 | 0 | 1.72 | 0 | 1.72 | INF | SAFER |
| M22 | -0.5 | -2.22 | -2.72 | -1 | 1.72 | 172.00 | SAFER |
| M23 | 1.029 | 0 | 1.029 | 0 | 1.029 | INF | SAFER |
| M24 | -0.5 | -1.529 | -2.029 | -1 | 1.029 | 102.90 | SAFER |
| M25 | -1.597 | -1.75 | -3.347 | -3.5 | 0.153 | 4.37 | N. SAFE |
| M26 | -0.5 | -0.653 | -1.153 | -1 | 0.153 | 15.30 | SAFER |
| M27 | -0.087 | 0 | -0.087 | 0 | 0.087 | INF | SAFER |
| M28 | 2.238 | 0 | 2.238 | 2.5 | 0.262 | 10.48 | N. SAFE |
| M29 | 2.143 | 0 | 2.143 | 2.5 | 0.357 | 14.28 | N. SAFE |
| M30 | 3.508 | 0 | 3.508 | 4 | 0.492 | 12.30 | N. SAFE |
| M31 | 3.46 | 0 | 3.46 | 4 | 0.54 | 13.50 | N. SAFE |
| M32 | 3.916 | 0 | 3.916 | 4.5 | 0.584 | 12.98 | N. SAFE |
| M33 | 3.916 | 0 | 3.916 | 4.5 | 0.584 | 12.98 | N. SAFE |
| M34 | 3.46 | 0 | 3.46 | 4 | 0.54 | 13.50 | N. SAFE |
| M35 | 3.508 | 0 | 3.508 | 4 | 0.492 | 12.30 | N. SAFE |
| M36 | 2.143 | 0 | 2.143 | 2.5 | 0.357 | 14.28 | N. SAFE |
| M37 | 2.238 | 0 | 2.238 | 2.5 | 0.262 | 10.48 | N. SAFE |
| M38 | -0.087 | 0 | -0.087 | 0 | 0.087 | INF | SAFER |
| M39 | -0.474 | -1.208 | -1.682 | -1.768 | 0.086 | 4.86 | N. SAFE |
| M40 | -0.372 | 2.274 | 1.902 | 1.768 | 0.134 | 7.58 | SAFER |
| M41 | -2.274 | 0.372 | -1.902 | -1.768 | 0.134 | 7.58 | SAFER |
| IVI42 | 1.208 | 0.474 | 1.682 | 1.768 | 0.086 | 4.86 | N. SAFE |
| IVI43 | -1.13 | 0.375 | -0.755 | -1.061 | 0.306 | 28.84 | N. SAFE |
| IVI44 | -1.054 | 2.45 | 1.396 | 1.061 | 0.335 | 31.57 | SAFER |
| IVI45 | -2.45 | 1.054 | -1.396 | -1.061 | 0.335 | 31.57 | SAFER |
| IVI40 | -0.375 | 1.13 | 0.755 | 1.061 | 0.306 | 28.84 | N. SAFE |
| IVI47 | -1.443 | 1.499 | 0.056 | -0.353 | 0.409 | 115.86 | N. SAFE |
| IVI48 | -1.418 | 2.19 | 0.772 | 0.353 | 0.419 | 118.70 | SAFER |
| N149 | -2.19 | 1.418 | -0.772 | -0.353 | 0.419 | 118.70 | SAFER |
| | -1.499 | 1.443 | -0.056 | 0.353 | 0.409 | 115.80 | N. SAFE |
| | -1.410 | 2.19 | 0.772 | 0.353 | 0.419 | 115.70 | |
| | -1.445 | 1.499 | 0.056 | -0.555 | 0.409 | 115.60 | N. SAFE |
| | -1.499 | 1.443 | -0.056 | 0.353 | 0.409 | 115.80 | N. SAFE |
| MSE | -2.19 | 1.418 | -0.772 | -0.353 | 0.419 | 21 57 | SAFED |
| MEE | -1.054 | 2.45 | 1.396 | 1.061 | 0.335 | 31.5/ | SAFER |
| | -1.13 | 0.375 | -0.755 | -1.061 | 0.306 | 28.84 | N. SAFE |
| | -0.375 | 1.13 | 0.755 | 1.061 | 0.306 | 28.84 | IN. SAFE |
| MSG | -2.45 | 1.054 | -1.590 | -1.001 | 0.335 | 51.57 | SAFED |
| MED | -0.372 | 2.274 | 1.902 | 1.708 | 0.134 | /.58 | |
| MG1 | -0.4/4 | -1.208 | -1.082 | -1./68 | 0.086 | 4.86 | N SAFE |
| MED | 1.208 | 0.474 | 1.082 | 1.768 | 0.086 | 4.80 | IN. SAFE |
| IVIUZ | -2.2/4 | 0.372 | -1.902 | -1./08 | 0.134 | 7.58 | JAFEN |

By, quick looking at the results, there are quite a few members which has a predicted unsafe loading and big percentages in the diamond braces. So, I don't think this is a good preliminary design. I don't think two-stage method can be applied for this truss, even with a modified version.

BALTIMORE TRUSS

Baltimore truss was invented in 19th century for the use in a railroad construction between Baltimore-Ohio-Pennsylvania Railroad. It is a Pratt Truss with extra members to prevent second order effects. (Info reference: HistoricBrigdes.org)

Pratt Truss:

AREAS

Baltimore Truss with smaller span:

Baltimore Truss:





Analysis of Baltimore Truss? Is it even necessary to apply two-stage method?

Although, in reality, some connections in a Baltimore truss can be rigid, a Baltimore truss can be modeled as a simple truss. This simple truss model will be stable and determinate. Modeling a Baltimore truss as a simple truss will result at the same exact axial forces with modeling it as a fixed truss. No shear or moments will be present. One big point of using the two-stage method is to try make the structure determinate and calculate forces. For a truss that can be modeled as determinate, there is no point of using an approximate indeterminate method.

So, in conclusion, two-stage method doesn't apply to this truss.

Here is some analysis to prove my points:



All ends fixed axial forces:



All ends released axial forces:



Using equation Degree of Static Determinacy = (number of members) – (2)(number of joints)+(number of reactions) $Ds = 45 - 2 \times 24 + 3 = 0 \Rightarrow$ determinate

FINK TRUSS

Designed and patented by Albert Fink in 19th century, fink truss was initially invented for railroad use. The axial only members used in a Fink truss is its speciality amongst other types. Currently it is used for smaller applications

Original patent drawing of Fink Truss:



Another version of fink truss (like our version):



Fink Truss currently in use in Peru (like our version but smaller span):



Applicability of Two-stage method to the Fink Truss:

The Fink Truss given can be modeled with all pin connections like the Baltimore Truss. But, the degree of determinacy will be 4 meaning that the truss will be 4th degree statically indeterminate. Two-stage method suggest the removal of 4 members from top and 4 members from bottom chord. This is not possible here since removal of a single member from the top will change the way the truss behaves and will even cause instabilities. (The bridge collapses in non-engineering terms)

One reason behind the instabilities or weird behavior is that some members here are cables or tension-only members which can take very little or no compression. These members can be modeled as a regular member also (which is what I did for the software results of the original truss) but this will cause very bad approximations as soon as some members are removed.

Therefore, in the software analysis of some members removed truss, it is better to set up the tension members as tensiononly members with a buckling load of 0 which means that as soon as a tension-only member goes under compression, the solver assigns a value of 0 stiffness to that member basically removing it from analysis. Software results for the actual truss:



Member Axial Forces (kN)(Tension (+), Compression (-) Computer Results: First Order Linear Elastic Analysis



PAULI OR LENTICULAR TRUSS

Invented in 19th century by Berlin Iron Bridge company. They later mass produced these truss bridges and today this type of truss is still used in numerous modern bridges. (https://www.researchgate.net/profile/Amy_Cerato/publication/268286982)

Original patented drawing:



Lenticular truss like ours:





Analysis of Baltimore Truss. Application of two-stage method and commentary:

Software Graphical Results:



Numerical Application of The Two-Stage Method (Member Labeling on next page):

| Member | Axial Forces From | Axial Forces From | Sum of Axial | Axial Forces From | Absolute Difference | Percent Error | SAFER OR |
|--------|---------------------|----------------------|------------------|-------------------|----------------------|----------------|----------|
| Label | First Stage (kN)(1) | Second Stage (kN)(2) | Forces (1+2)(kN) | Software (kN) | of Axial Forces (kN) | Per Member (%) | NOT |
| M1 | 0 | -2.573 | -2.573 | -2.599 | 0.026 | 1.00 | N. SAFE |
| M2 | 0 | -2.371 | -2.371 | -2.395 | 0.024 | 1.00 | N. SAFE |
| M3 | 0 | -2.263 | -2.263 | -2.286 | 0.023 | 1.01 | N. SAFE |
| M4 | 0 | -2.263 | -2.263 | -2.286 | 0.023 | 1.01 | N. SAFE |
| M5 | 0 | -2.371 | -2.371 | -2.395 | 0.024 | 1.00 | N. SAFE |
| M6 | 0 | -2.573 | -2.573 | -2.599 | 0.026 | 1.00 | N. SAFE |
| M7 | 2.573 | 0 | 2.573 | 2.549 | 0.024 | 0.94 | SAFER |
| M8 | 2.371 | 0 | 2.371 | 2.348 | 0.023 | 0.98 | SAFER |
| M9 | 2.26 | 0 | 2.26 | 2.237 | 0.023 | 1.03 | SAFER |
| M10 | 2.26 | 0 | 2.26 | 2.237 | 0.023 | 1.03 | SAFER |
| M11 | 2.371 | 0 | 2.371 | 2.348 | 0.023 | 0.98 | SAFER |
| M12 | 2.573 | 0 | 2.573 | 2.549 | 0.024 | 0.94 | SAFER |
| M13 | -1.75 | -1.75 | -3.5 | -3.5 | 0 | 0.00 | EQUAL |
| M14 | 0 | 0 | 0 | 0 | 0 | 0.00 | EQUAL |
| M15 | -2.25 | 2.249 | -0.001 | 0.044 | 0.045 | 102.27 | N. SAFE |
| M16 | -2.25 | 2.249 | -0.001 | 0.044 | 0.045 | 102.27 | N. SAFE |
| M17 | -2.25 | 2.249 | -0.001 | 0.044 | 0.045 | 102.27 | N. SAFE |
| M18 | -2.25 | 2.249 | -0.001 | 0.044 | 0.045 | 102.27 | N. SAFE |
| M19 | -2.25 | 2.249 | -0.001 | 0.044 | 0.045 | 102.27 | N SAFF |
| M20 | -2.25 | 2.249 | -0.001 | 0.044 | 0.045 | 102.27 | N. SAFE |
| M21 | -0.5 | 0 | -0.5 | -0.495 | 0.005 | 1.01 | SAFER |
| M22 | -0.5 | 0 | -0.5 | -0.495 | 0.005 | 1.01 | SAFER |
| M23 | 0.0 | 0 | 0.0 | 0 | 0 | 0.00 | FOUAL |
| M24 | -0.5 | 0 | -0.5 | -0.495 | 0.005 | 1.01 | SAFER |
| M25 | -0.5 | 0 | -0.5 | -0.495 | 0.005 | 1.01 | SAFER |
| M26 | -0.5 | 0 | -0.5 | -0.495 | 0.005 | 1.01 | SAFER |
| M27 | -0.5 | 0 | -0.5 | -0.495 | 0.005 | 1.01 | SAFER |
| M28 | 0.9 | 0 | 0.5 | 0.455 | 0.009 | 0.00 | ΕΟΠΑΙ |
| M29 | -0.5 | 0 | -0.5 | -0.495 | 0.005 | 1 01 | SAFER |
| M30 | -0.5 | 0 | -0.5 | -0.495 | 0.005 | 1.01 | SAFER |
| M31 | 0.9 | 0 | 0.5 | 0 | 0.003 | 1.01 | |
| M32 | -0.5 | 0 | -0.5 | -0.495 | 0.005 | 1.01 | SAFER |
| M32 | -0.5 | 0 | -0.5 | -0.455 | 0.005 | 1.01 | |
| M34 | -0.5 | -1 75 | -0.5 | -0.455 | 0.005 | 1.01 | |
| M25 | -1.75 | -1.75 | -3.5 | -3.5 | 0 | 0.00 | EOUAL |
| Mae | 0 | 0 | 0 | 0 | 0 | 0.00 | EQUAL |
| M27 | 0 | 0 | 0 | 0 | 0 | 0.00 | EQUAL |
| N120 | 0 | 0 | 0 | 0 | 0 | 0.00 | |
| M30 | 0 | 0 | 0 | 0 | 0 | 0.00 | EQUAL |
| M40 | 0 | 0 | 0 | 0 | 0 | 0.00 | EQUAL |
| N/40 | 0 | 0 | 0 | 0 | 0 | 0.00 | EQUAL |
| MA2 | 0 | 0 | 0 | 0 | 0 | 0.00 | EQUAL |
| N142 | 0 | 0 | 0 | U | 0 | 0.00 | EQUAL |
| N145 | 0 | 0 | U | U | 0 | 0.00 | EQUAL |
| N/44 | 0 | 0 | U | U | 0 | 0.00 | EQUAL |
| IVI45 | 0 | 0 | 0 | U | 0 | 0.00 | EQUAL |
| | 0 | 0 | 0 | 0 | 0 | 0.00 | EQUAL |
| IVI47 | 0 | 0 | 0 | 0 | 0 | 0.00 | |
| IVI48 | 0 | 0 | 0 | 0 | 0 | 0.00 | EQUAL |



Two stage method can be applied to this truss due to the similarities of it to the example truss given. It also gives surprisingly good results, almost identical to the original truss. The 102.27% "Not safes" are just very small numbers to be ignored.

Part e, possible limitations of the proposed method:

1)<u>Nonlinear analysis</u>: In nonlinear analysis, superposition principle is not valid therefore two stage method is not appropriate. Also, compression members will buckle leading to improper estimations of forces.

2)<u>Vertical Load not symmetric</u>: It can be used for calculating the top and bottom chord forces of the truss. However, for the braces, the estimates will be off. If the loads are small, might be acceptable. Otherwise, this method should be avoided for asymmetrical or non-uniform vertical loading.

An example where this method is not appropriate for the entire structure, tension (-):



The not symmetric loading case was analysed also by the author of this report and the following two report contains some additional information:

http://www.sci-en-tech.com/ICCM2017/PDFs/2486-9688-1-PB.pdf

http://www.mechanik.media.pl/pliki/do_pobrania/artykuly/22/2017_07_s0585_eng1.pdf

3)<u>Horizontal loading</u>: This will not work because as soon as some members from top or bottom chord are removed, it will change the forces of the bracing.

4)<u>Temperature loading and fabrication errors</u>: This won't work because these are not equivalent to a uniform vertical load.

Part f, my opinions on the paper and possible mistakes that the paper contains:

This paper was written by an engineer that has focuses on building design according to his other published work. So, the methods described in this paper are intended for the specific simple trusses that he works with. I think this paper is more focused on buildings then bridge trusses. In terms of professionality, I don't think the paper was checked professionally. There shouldn't be basic mistakes on a published report.

In 2018, almost 2019, I would not recommend such a method. It only applies to specific cases, there are a lot of limitations and more calculation efforts. In his conclusion, the author mentioned about the simplicity of the method, but we are living in an age where computers became very powerful and very portable. A portable computer can easily do 10^10 floating point operations per second and we enough ram to store huge matrices. Using finite element analysis, indeterminate structures of such a small scale can be solved within seconds and with very good accuracy. Linear analysis is currently not an issue. Hand calculation checks are still done but not for such simple things.

I pointed out some numerical mistakes in the part b of this report. I won't repeat those here. Other then those, there is a conceptual mistake on a part of this report. He says tension members to compression members:



Figure 1. Simplified schemes of basic form of a tension-strut truss

When to the truss are applied forces of too big values as it is allowed, what is conditioned by the appropriate pre-stressing, one can notice that some of the tension members, e.g. of the upper layer, do not participate in the force transmission, what is shown in Fig. 1b. From analysis of this figure follows, that a truss being the statically