WIM data analysis for the fatigue lifetime evaluation of standard steel truss bridge elements

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Abstract. Bridge in Indonesia is designed using bridge loading standard SNI 1725:2016. Bridge is an infrastructure that withstands dynamic and repetitive loading. Vehicle load in this regulation are idealization of actual vehicle load. Weigh in motion (WIM) technology allow the measurement of vehicle load when vehicles moving, which is the actual load of traffic received by road and bridge. The effect of this loading on the bridge element, especially steel girder on Steel Truss Bridge type, there is repetitive occurrence of stress and relaxation due to vehicle loading in service life that can make the bridge failed due to fatigue. The purpose of this research is to evaluate the fatigue lifetime of steel truss bridge elements due to projection of accumulated vehicle load from WIM data. The bridge that will be evaluate on this research is 60 meters span steel truss bridge using WIM data of the Kaligawe Bridge, Semarang. This analysis was conducted by using stress range-number of cycles from structural analysis of accumulated WIM vehicular load, and compared to nominal fatigue resistances using stress range cycles-number curve (S-N curve). Evaluation method of fatigue with S-N curve method are specified in SNI and AASHTO. Evaluation results indicated that the fatigue limit of 50 year lifetime services on S-N curve which has not been surpassed and projected, the fatigue lifetime of the bridge would be on the 54th.

1. Introduction
Traffic volume and vehicle load are necessary factors in designing bridge structures. Traffic volumes and vehicle loads are primary data which requires profound and accuracy in its collecting process to obtain maximum results. Vehicle load measurement technology continues to develop, one of these measuring vehicle load technologies is weight in motion (WIM). WIM technology allows measurement of vehicle loads while it moving, as it is actual load of traffic received by roads and bridges. Also, fatigue limit state is required at RSNI T-03: 2005 and SNI 1725: 2016 in order to prevent the bridge from running into fatigue failure due to its lifetime. For this purpose, this research analyzes the stress range of a planned a truck load on the number of loading cycles that are assumed to occur during the lifetime of the bridge plan [1], [2], [3].

2. Method and materials
2.1. Sample Preparation
WIM data measurement of actual traffic loads used the Kaligawe Bridge - Semarang WIM data during 7 days from November 1 - 7, 2018. Data was obtained from the Road and Bridge Research and Development, Kementrian Pekerjaan Umum dan Perumahan Rakyat. The Kaligawe Bridge is a national road located in Kelurahan Tambakrejo, Kecamatan Gayamsari, Semarang City, Central Java Province.
Technical specifications for a 60 m span bridge:

1) Type of steel truss bridge: Warren truss with vertical bracing
2) Strength class and span: A class, 60 m
3) Bridge length: 60 m
4) Bridge width: ±9.7 m center to center
5) Bridge height: ±6.4 m

All frames element must have steel strength minimum at ASTM A572 Grade 50 or EN 10025 Grade S355 JO or AASHTO M270 which are equivalent to SNI-07-7178-2006 BJ55 strength as the minimum yield stress ($F_y$) requirement amount of 345-410 MPa and a minimum ultimate stress ($F_u$) requirement amount of 450-550 MPa. All profiles size refer to variations in the dimensions in JIS G3192.

![Steel truss bridge components](image)

**Figure 1.** Steel truss bridge components

2.2. Method

This research is using evaluation research method with a quantitative approach. WIM data consists of recapitulated total of vehicle load to see the total load distribution of vehicles that passing by, and make projections of the bridge service lifetime for 50 years. Bridge structure technical data is used for creating structural models as the structural analysis process. After the structural model have created, the structure is loaded using each total vehicle load from WIM processing data. The output of these structural modeling and analysis process are the range of stresses due to each vehicle's total load. Recapitulation of the stress range and frequencies from the results are used for evaluation of nominal fatigue resistance by combining them on the S-N curve, so the bridge service-age is obtained [4], [5], [6].
3. Results and discussion

3.1. WIM data analysis

Vehicle total load data and it’s frequency occurrence from WIM data analysis results are used in the structural model load. Each vehicle total load is applied as a moving load on the structural model. The purpose is to calculate the frequency rate and the stress range that occur due to the total load of the vehicle on each frame elements of the standard steel truss bridge and will be evaluated in this research.

| Class | Lane 1 Amount | Frequency | Lane 2 Amount | Frequency |
|-------|---------------|-----------|---------------|-----------|
| 1     | 28            | 0.19%     | 7             | 0.93%     |
| 2     | 7446          | 50.92%    | 328           | 43.50%    |
| 3     | 1273          | 8.70%     | 86            | 11.41%    |
| 4     | 6             | 0.04%     | 0             | 0.00%     |
| 5     | 3461          | 23.67%    | 182           | 24.14%    |
| 6     | 155           | 1.06%     | 3             | 0.40%     |
| 7     | 15            | 0.10%     | 0             | 0.00%     |
| 8     | 31            | 0.21%     | 0             | 0.00%     |
| 9     | 22            | 0.15%     | 2             | 0.27%     |
| 10    | 131           | 0.90%     | 7             | 0.93%     |
| 11    | 1122          | 7.67%     | 74            | 9.81%     |
| 12    | 108           | 0.74%     | 4             | 0.53%     |
| 13    | 13            | 0.09%     | 0             | 0.00%     |
| 14    | 3             | 0.02%     | 0             | 0.00%     |
| 15    | 77            | 0.53%     | 4             | 0.53%     |
| 16    | 90            | 0.62%     | 4             | 0.53%     |
| No | Total Load (ton) | Lane 1 | Lane 2 |
|----|-----------------|-------|-------|
|    | n               | f     | n    | f    |
| 1  | <10             | 7474  | 51.11% | 335  | 44.43% |
| 2  | 10-20           | 5115  | 34.98% | 282  | 37.40% |
| 3  | 20-30           | 1255  | 8.58%  | 81   | 10.74% |
| 4  | 30-40           | 777   | 5.31%  | 56   | 7.43%  |
| 5  | 40-50           | 0     | 0.00%  | 0    | 0.00%  |
| 6  | 50-60           | 0     | 0.00%  | 0    | 0.00%  |
| 7  | 60-70           | 3     | 0.02%  | 0    | 0.00%  |
|    | Total           | 14624 | 100.00% | 754  | 100.00% |

**Table 2.** Result frequency of total vehicle load

**Figure 3.** Histogram of total vehicle load for Lane 1 and 2

**Figure 4.** Vehicle load as moving load in the model
3.2. Result
The maximum and minimum stresses on each steel truss element are recapitulated for the entire load of the vehicle from WIM data analysis. Below is the result of stress ranges obtained:

| No | Vehicle Load | Stress Max. (MPa) | Stress Min. (MPa) | Stress Range (MPa) |
|----|--------------|-------------------|-------------------|-------------------|
| 1  | 10           | 19.49             | -20.28            | 39.770            |
| 2  | 20           | 39.859            | -39.884           | 79.743            |
| 3  | 30           | 59.736            | -59.648           | 119.384           |
| 4  | 40           | 88.8              | -88.552           | 177.352           |
| 5  | 50           | 111               | -110.69           | 221.690           |
| 6  | 60           | 133.2             | -132.828          | 266.028           |
| 7  | 70           | 155.401           | -154.966          | 310.367           |

Subsequently, the maximum stress data distribution of the element is converted into frequency data of the stress range distribution. The number of cycles of each vehicle which is the weight of the total accumulated amount, is projected during the age plan of the bridge for 50 years with the assumption of vehicle growth is 11.25%. Frequency data of each stress range is evaluated using S-N curve.

| No | Stress Range (MPa) | Lane 1 | Lane 2 |
|----|--------------------|--------|--------|
|    |                    | n      | f      | n      | f      |
| 1  | 30-40              | 72,153,500 | 51.11% | 3,234,068 | 44.43% |
| 2  | 40-50              | 49,379,870 | 34.98% | 2,722,409 | 37.40% |
| 3  | 50-60              | 12,115,687 | 8.58%  | 781,969  | 10.74% |
| 4  | 60-70              | 7,501,106  | 5.31%  | 540,620  | 7.43%  |
| 5  | 70-80              | -       | 0.00%  | -       | 0.00%  |
| 6  | 80-90              | 28,962  | 0.02%  | -       | 0.00%  |
|    | Total              | 141,179,125 | 100.00% | 7,279,066 | 100.00% |

Figure 5. S-N curve fatigue evaluation lifetime with 50 years cycle projection
At the stress range effect > 60 Mpa, as projected using a dashed line in order that the cycle of the strain span effect touches and exceeds the nominal fatigue resistance curve achieved around 11,490,142 cycle (n). The cycle value for 50 years reaches 7,501,106 cycles, thus to exceed the nominal fatigue resistance curve can be achieved with projections from traffic data that is 54 years in service lifetime.

4. Conclusion

Based on the fatigue evaluation of the S-N curve method for the steel truss bridge with a 60 meter Bina Marga standard span bridge system, caused by the vehicle load by WIM data in Kaligawe - Semarang, it was found that the stress cycle due to loading of accumulated vehicles resulting from WIM data analysis for 50 years still did not exceed the S-N curve, which means the fatigue age has not been exceeded. Thus, the Bina Marga standard steel truss bridge type which is widely applied in various national roads in Indonesia, still meets the criteria for fatigue lifetime limits $\gamma (\Delta f) \leq (\Delta F) n$ as stipulated in the planning standard of SNI 1725: 2016 (BSN 2016) and AASHTO LRFD Bridge Design Code.

5. References

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