Automation of evaluation of data measured on steel bridges, category detail of welded lamellas

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Automation of evaluation of data measured on steel bridges, category detail of welded lamellas

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Abstract. The paper introduces an automatic data evaluation system on the server or on the connected PC to it via SW ALERT and POKOF. The system prepares measurement results for the graphical representation on the PC screen not only of the daily files but also of the selected period. The results of the fatigue assessment are stored in a permanently supplemented text file. Design of detail category of welded lamellas on the basis of fatigue tests.

1. Automation of evaluation of data measured on steel bridges

The automatic evaluation of the measured data was developed at the time of the construction of the steel-concrete bridge over the Lochkov valley. Measurement using strain gauges and thermocouples placed on the carrier welds of the lamellas was started out from the beginning of the assembly of the bridge to its gradual assignment of welded parts of the bridge, the concrete road and the first few years of the operation of the bridge. The written records of the assembly run are possible to assign the measured data to them. Five EMS DV 803 fully-equipped measuring units were used. The built-in system for the automatic evaluation of the measured data allowed to omit the evaluation process and thereby reduce the cost of processing. There was no detail category available for evaluating the damage to the welded joints by the fatigue process. Thanks to support from the state budget, his suggestion was based on fatigue tests of large test sticks made from welded joint at a scale of 1:1.

The strain gauges, accelerometers, displacement meters, deflectors, and temperature sensors are commonly used to determine the response of bridges' steel structures to operational loads, including climatic loads and possible seismic effects. For normal measurements, sampling of measured data is usually 25 Hz or 12.5 Hz. In order to evaluate the response to rapidly changing events, measured e.g. accelerometers, it is necessary to specimen the measured data, e.g. by the frequency of approx. 400 Hz. The large amount of data is measured, if the bridge is equipped with up to 60 sensors. The sampling of measured 400 Hz data is usually performed for up to 15 minutes. The measuring system must allow the sampling of the measured data to be switched at a distance.

It is expedient to transfer the measured data, for example, by a GSM system to the server of the organization owning the bridge, or to carry out a measurement evaluation. The data files should be closed every day after midnight and ready for immediate evaluation. Measured data are assessed by the automatic system on the server or on the connected PC. Using of the SW ALERT and POKOF allow specialists not to be burdened by routine activities, but they can engage in other highly
specialized activities. The system prepares measurement results for the graphical representation on the PC screen not only of the daily files but also of the selected period. The results of the fatigue assessment are stored in a permanently supplemented text file.

The measured data transported to the server are stored in one folder named eg MOSTD1. Suppose we have two daily files, labeled: DRRMMD_001.EMS and DRRMMD_002.EMS. The letters RR denote the year, MM denotes the month and DD denote the day. The digits for underscores indicate the serial number of the measuring device.

On the bridge, for example, sensors are located in two areas, far apart. To shorten the length of the interconnection wires between the sensors and the measuring device, each of the two measuring units is placed as close as possible to the sensors. Then the same types of sensors can be found in both measuring panels. However, we have the interest to separately evaluate: 1) separate strain gauges G together with strain gauges placed in the T shape, including the measured temperatures; 2) separately R - rosettes of strain gauges, including the measured temperatures; 3) separately displacement meters P, including the measured temperatures; 4) separately accelerometers A, including the measured temperatures.

To speed up the evaluation of the measured data, we decide that each of the four groups will be processed on separate subfolders. We will call subfolders MOSTD1GT; MOSTD1R; MOSTD1P; MOSTD1A. This division also has the advantage if the transmission of the measured data from the measuring devices to the server is interrupted for several days, and their evaluation would have to perform retrospectively. Therefore, it is necessary to have a time reserve, daily evaluation must take place in a much shorter time than 24 hours. Each case of measurement on a operated bridge may be different. Therefore, for each measurement case, the control program will be modified and appropriately labeled. In this case, this is a modification called ALERTD1.

SW ALERTD1 in the present case, when the daily data files DRRMMD_001.EMS and DRRMMD_002.EMS are closed, creates the four text files. In doing so, it will keep the order of the sensors according to the input it has available to solve the task. Lastly, it usually stores compensatory strain gauges, when they are used, and temperature sensors, again in the specified environment. In this example, the following files are created: DRRMMDG.TXT, which is sent to the MOSTD1GT subfolder; DRRMMDR.TXT, which is sent to the MOSTD1R subfolder; DRRMMDP.TXT, which is sent to the MOSTD1P subfolder; DRRMMDDA.TXT, which is sent to the MOSTD1A subfolder.

Figure 1. The displacements of the measured bridge LP01 and LP03 in the longitudinal direction and LP02 in the transverse direction relative to the support on the side of Plzen town and the displacement LP04 and LP06 in the longitudinal direction and LP05 in the transverse direction relative to the support on the side of Brno town. They were measured throughout the year from 17.11.2016 to 16.11.2017, [3].
After that, the SW ALERTD1 control runs on each subfolder the POKOF evaluation software, currently it is a version 8 to 10. The SW POKOF for its operation needs the auxiliary files that are installed on each of the sub-tabs, such as the header of output text files with the symbol DBX after the dot. In some cases, a large number of calculated variables can be assessed, and SW POKOF can be entered to base the results on several DBX output text files. To distinguish them, the first letter "D" in the output files is replaced with the letters "A", "B", "C", eg ARRMMDDR.DBX. In all cases, these are daily closed text files. The first column in all TXT and DBX text files represents the time and is taken from the base file with the EMS end, again according to the prescribed protocol. If a fatigue assessment is entered, the accumulation results of fatigue damage for a given day for the rated site are stored on the appropriate text file. For example, text files for example would be labeled VMOSTD1G.TXT and VMOSTD1R.TXT.

The SW MONITOR supplied to the EMS DV 803 measuring devices allows to combine the result sets into the file DBX for a period for which the results are available. For example, for a year or three years it is possible to plot the shifts of the bridge over the supports, Figure 1. The ALERT control program can also be complemented by other features, such as sending SMS messages or emails about unusual situations, such as unexpected interruptions in measured data transmission or unexpected stresses, shifting, and so on.

2. Experimental determination of the category detail of welded lamellas.

The welded lamellas joint of two lamellar flanges, is not listed as the "category of detail" in EN 1993-1-9 [2] or CSN 27 7008 [3]. The paper presents the results of fatigue tests of test specimens made from the 1:1 welded lamellar flanges, which were stressed both in the area of high-cycle fatigue (HCF) and in the area of low-cycle fatigue (LCF). The results of the fatigue tests were compared with the fatigue assessment using fatigue strength curves experimentally measured on standard test specimens [5].

The 1:1 welded lamella flanges model was made of S355NL + N and S355K2 + N steels. Both are classified as quality steel, used for steel structures, even at low temperatures. Two lamella flanges of 60x1200x2000 mm were made of S355NL + N steel. The lamellae flange measuring 45x1260x1950 mm was made of S355K2 + N steel. It is the material used for the same weld joint of the lamella flanges on a steel-concrete bridge, as built over the Lochkovské Valley on the southwest highway bypass of Prague. The model 1:1 of this welded joint was produced by Bögl - Krysl, k.s., which also carried out assembly welds on the bridge across the Lochkov Valley.

The sheets used for the production of the test model were rolled in the longitudinal direction, the carrier weld of the lamella flanges being perpendicular to the rolling direction. The longitudinal axis of test specimens made from the 1:1 model coincides with the direction of rolling. After measuring residual stresses by the drilling method, the model of 3900 mm length was shortened to 800 mm (400 mm on each side of the longitudinal axis of the weld), ie to the required length of the test specimens, Figure 2.

The test specimens were equipped with strain gauges to determine the distribution of the cyclically variable loading force in both lamellar flanges and to identify the number of cycles at which the fatigue crack initiates. A fatigue crack occurred at the seam weld root (Figures 4-9) of the lamella flanges with a wall thickness of 45 mm. Following this finding, the four strain gauges (G5 to G8) were transferred to the place of the fatigue crack on other test specimens (Figure 2). The number of load cycles $N_p$, in which the plastic deformations are the first formed in the region of the sealing weld root, as well as the number of cycles at which the fatigue crack of the $N_{in}$, so they were determined as accurately as possible. According to standards, eg [2] and [3], the lifetime of the steel structure is calculated into the initiation of the fatigue macro crack of about 0.5 mm, with a probability of 5% (PP05).
Figure 2. Dimensions of the carrier and sealing welds.

Figure 3. Place the strain gauges on the test specimen after the fatigue crack was detected. G5 to G8 were used to determine the number of cycles at the crack initiation.

Figure 4. Specimen No.17 suspended in the test frame before the fatigue test in the HCF area.

Figure 5. Specimen No. 6 after the fatigue test in the LCF area, terminated by broken.

Figure 6. Specimen No. 6, view of the fracture area.

Figure 7. Specimen No. 8 after the end of the fatigue test. Crack formation was initiated at the sealing weld.
In the standard EN 1993-1-9 [1] the dependence of $\Delta \sigma = f (N)$ is plotted in the range of $10^4$ to $10^9$ cycles. The specimens were tested from the beginning of this range to $2 \times 10^7$ cycles, both in the LCF and in the HCF area. The results of the cyclic loading of the test rods in the LCF and HCF areas are graphically illustrated in Figure 11. The potted points represent the results in which a fatigue macrocrack of about 0.5 mm in size occurred in the area of the timed strength to the number of cycles $N_D = 5000000$. Results are also plotted when the crack did not occur, or cyclic loading was completed at $2000000$ cycles. These range of stresses were even greater than measured on a real bridge across the Lochkov Valley [4] and [5].

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**Figure 8.** Crack detail in specimen No. 11. Crack formation was initiated at sealing weld. These trajectory was the only one case.

**Figure 9.** Detail of crack in specimen No.26. Crack formation was initiated at sealing weld. The crack in the 60 mm lamella began to emerge later.

**Figure 10.** Specimen No. 27, the course of average and bending stresses $\sigma_{m,1-4}$ and $\sigma_{b,1-4}$ to $\sigma_{m,5-8}$ and $\sigma_{b,5-8}$ [MPa] of the measured G1 to G8 strain gauges. Load force $F$ [1 kN = 1 unit]. The resulting crack in the 45 mm lamellar flange was passed through the G6 and G7 strain gauges, see Figure 3. In the second 60 mm lamellar flange, the fatigue crack did not occur, the G5 and G8 strain gauges therefore did not record their occurrence.
The 8 specimens were tested in the LCF area and the 13 specimens in the HCF area, the total of 21 specimens. However, in the timed strength area to $\Delta \sigma_0$, the fatigue crack occurred in only 12 specimens of 21. Measured fatigue strength curves evaluated for both PP 50% and PP 05% are plotted in Fig. 11.

Dependence the range of nominal stresses $\Delta \sigma_{nom}$ on the number of cycles $N_o$, until the beginning of fatigue crack initiation of the size $a = 0.5$ mm, can be written in the form:

1) The fatigue strength curve with a probability of failure PP50 % $y = -0.3007x + 3.6848$ can be expressed in the range of $10^4$ to $5 \times 10^6$ cycles in the form:

$$N_O = N_C (\Delta \sigma_C/\Delta \sigma_n)^{3.007},$$  
(1)

in which the number of cycles $N_C = 2 \times 10^6$ corresponds to the range of stresses $\Delta \sigma_C = 61.67$ MPa.

2) The fatigue strength curve $y = -0.3159x + 3.6899$ in the range of $10^4$ to $5 \times 10^6$ cycles determined by the least squares method was interpolated by experimentally measured points reduced to PP05%. It can be expressed in the form:

$$N_O = N_C (\Delta \sigma_C/\Delta \sigma_n)^{3.166},$$  
(2)

in which the number of cycles $N_C = 2 \times 10^6$ corresponds to the range of stresses $\Delta \sigma_C = 50.05$ MPa. Exponent 3.166 is close to exponent 3, which uses standards [1] and [2] in the range of cycles $10^4$ to $5 \times 10^6$.

3) Fatigue strength curve PP05% $y = -0.2096x + 2.9776$ in $N_D = 5 \times 10^6$ cycles up to $1 \times 10^8$ cycles, represent the linear curve (2) for $N_D = 5 \times 10^6$ cycles with the test terminated near $10^8$ cycles. This can be expressed in the form:

$$N_O = N_D (\Delta \sigma_D/\Delta \sigma_n)^{4.771},$$  
(3)

in which the number of cycles $N_D = 5 \times 10^6$ corresponds to the range of stresses $\Delta \sigma_D = 37.47$ MPa. Exponent 4.771 is close to exponent 5, which uses standards [1] and [2] in the range of cycles $5 \times 10^6$ to $1 \times 10^8$.

4) Permanent strength limit of range stresses $\Delta \sigma_L = 20.26$ MPa for the number of cycles $1 \times 10^8$ and above can be calculated from $y = 1.3066$.

![Figure 11](image-url)

**Figure 11.** The red line applies in the region of $N_i = 10^4$ to $5 \times 10^6$ cycles; the orange line is in the $N_i = 5 \times 10^6$ to $1 \times 10^8$ region and the purple line in the area of the permanent strength above $N_i = 1 \times 10^8$ cycles.
Fatigue tests have shown that the fatigue crack originated first at the sealing weld root of the lamellar flange with a wall thickness of 45 mm and then started in a 60 mm thick lamellar flange at the same root of the sealing weld. On the other side of the carrier weld, where both lamellar flanges had a wall thickness of 60 mm, no fatigue crack was found on any specimen’s test even when cycling loading continued to rapture of the specimens.

3. Conclusions

Using of the SW ALERT and POKOF allow specialists not to be burdened by routine activities, but they can engage in other highly specialized activities.

Conclusions from the fatigue tests can be generalized for design of welds of lamellar flanges with a wall thickness of up to 60 mm. According to EN 1993-1-9, the detail category of $\Delta \sigma_C = 50$ MPa can be taken for it. The fatigue strength curves for the wall thicknesses of 25 mm are plotted in EN 1993-1-9. According to the experiment, the detail category $\Delta \sigma_C = 50,05/(25/60) 0,2 = 59,63$ MPa would correspond to a thickness of 25 mm, falling within range of detail category 56 MPa to 63 MPa.

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