

EXERCISE FAT4: CUMULATIVE DAMAGE – CORRECTION

PROBLEM 1

1. Detail Category

These details are vertical stiffeners welded to a plate girder flange. They correspond to Detail 7 of Table 8.4 and their detail category is 80 because L is less than 50 mm (stiffeners generally between 10 and 12 mm thick and fillet welds size 5 mm or max 6 mm).

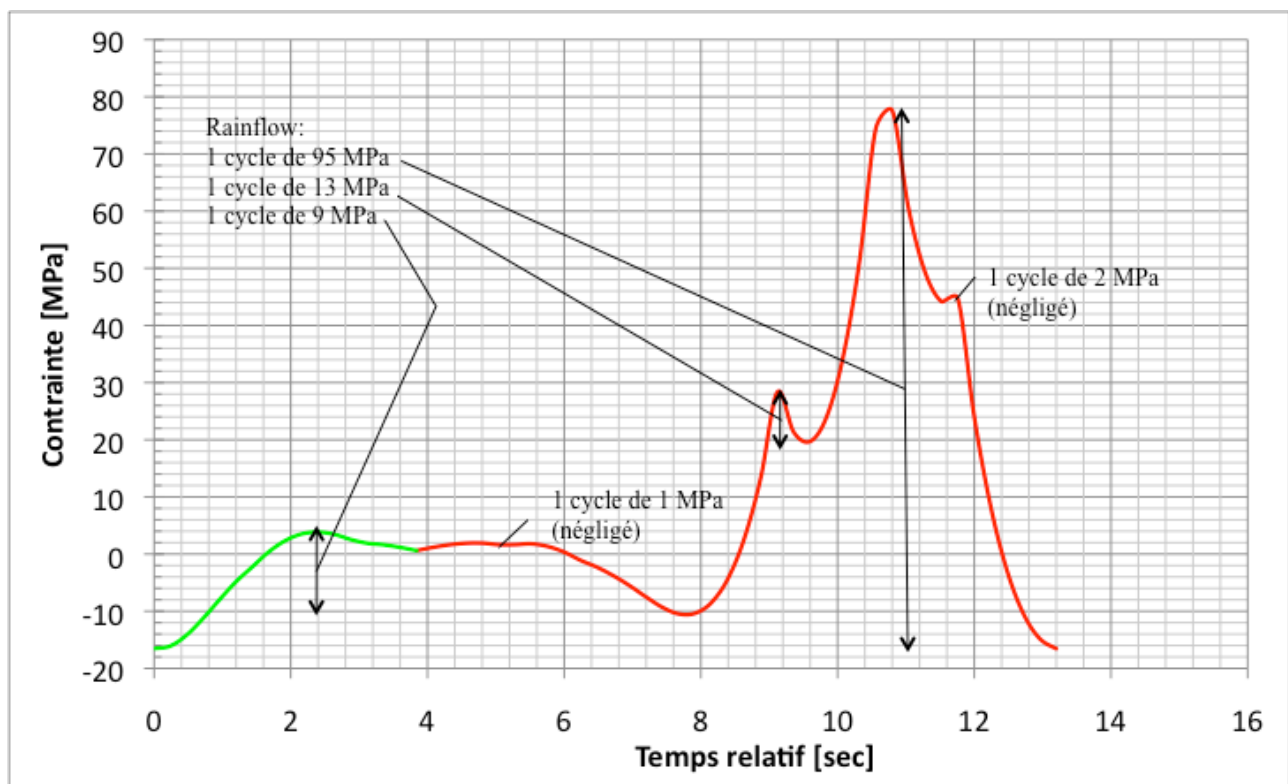
2. Cumulative Damage

a. Stress ranges or differences

By applying the reservoir method (need to start from the minimum, thus moving the green part, then filling and emptying "upside down". One would get the same result if starting from the maximum and moving another part, then filling normally), the following stress differences are obtained:

$$\Delta\sigma_1 = 95 \text{ N/mm}^2, \Delta\sigma_2 = 13 \text{ N/mm}^2, \Delta\sigma_3 = 9 \text{ N/mm}^2$$

There are cycles of very small differences that can be overlooked ($\Delta\sigma_4 = 2 \text{ N/mm}^2, \Delta\sigma_5 = 1 \text{ N/mm}^2$).



b. Number of cycles

It is considered that 6 trains per hour will run 16 hours per day, 365 days per year for 70 years, for a total of 2,452,800 trains. Each train induces the cycles given under a), and it is assumed for simplicity that all trains are identical and that there is no change of equipment during the service life (simplifying assumption, in reality one usually has to add up cycles from different train types circulating on a line).

c. Cumulative Damage

To express the cumulative damage at the design level (incl. partial load and resistance factors), the following relationships are used:

$$D_i = \frac{n_i}{N_i} \text{ and } N_i = C_1 \cdot (\gamma_{Ff} \cdot \Delta\sigma_i)^{-m}$$

1st case: $\Delta\sigma_i > \Delta\sigma_D/\gamma_{Mf}$ and therefore $m = 3$

$$D_i = \frac{n_i}{N_i} = \frac{n_i}{C_1 \cdot (\gamma_{Ff} \Delta\sigma_i)^{-m}}$$

We obtain the expression for C_1 from the resistance curve expressed at 2 million cycles:

$$C_1 = 2 \cdot 10^6 \cdot (\Delta\sigma_C/\gamma_{Mf})^m$$

The values of the partial factors are chosen as follows:

- Load factor: $\gamma_{Ff} = 1.0$ (almost always the case)
- Resistance factor: $\gamma_{Mf} = 1.15$ (consequence of failure large, damage-tolerant element because cross-section with 2 beams and which are continuous beams)

For the construction detail $\Delta\sigma_c = 80 \text{ N/mm}^2$, we obtain: $C_1 = 6.733 \cdot 10^{11} \text{ (cycles)} \cdot (\text{N/mm}^2)^3$

We can do the same for the 2nd case: $\Delta\sigma_L/\gamma_{Mf} < \Delta\sigma_i < \Delta\sigma_D/\gamma_{Mf}$ with $m_2 = 5$ in order to obtain a C_2 value, but this is not necessary in this exercise (because there is no $\Delta\sigma_i$ in this area).

3rd case: $\Delta\sigma_i < \Delta\sigma_L/\gamma_{Mf}$, then $D_i = 0$

The sum of all partial damages is shown in the table below:

$\Delta\sigma_i$	Case	n_i	M	n_i	$Di = n_i/N_i$
95	$> \Delta\sigma_D/\gamma_{Mf}$	2452800	3	785300	3.123
13	$< \Delta\sigma_L/\gamma_{Mf}$	2452800	-	∞	0
9	$< \Delta\sigma_L/\gamma_{Mf}$	2452800	-	∞	0

$$D_{tot} = \mathbf{3.123}$$

The sum of all the partial damage makes it possible to establish a total damage $D_{tot} = 3.123$, well above 1.0, which means that the detail studied cannot reach the 70-year service life !

Note: not considering any fatigue limit, curve with single slope $m = 3$ (which is unfavorable) the result would be as follows:

$\Delta\sigma_i$	neither	M	Neither	ni/N_i
95	2452800	3	785300	3.123
13	2452800	3	3.065E+08	0.008
9	2452800	3	9.236E+08	0.003

$$D_{tot} = \mathbf{3.134}$$

The cumulative damage is therefore practically the same as before, which is a proof that the small stress ranges have little influence on the damage sum.

Note that this example is relatively straightforward, often the majority of stress cycles are located in the zone with the slope $m_2 = 5$ (2nd case).

3. Solutions to propose:

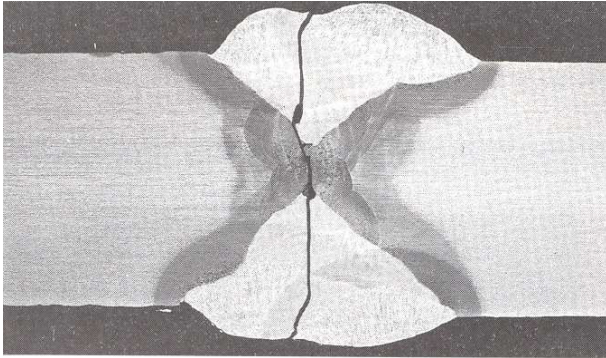
- a. Design with a more favorable detail (do not weld the stiffener on the flange, it must still play its role but if possible interrupt it above). We then have the same detail, but in the web, therefore subject to smaller stress differences. Otherwise, it is possible to consider a postweld treatment, which makes it possible to improve the category for this type of detail by 2 to 4 classes (80 -> 100, or even 125).
- b. Reduce stresses
 - i. Reinforce the flange with a coverplate – be careful, there is an unfavourable detail at the end of the coverplate (thus a detail to be located away from the large stress differences).
 - ii. Increase the thickness of the flange. The simplest but adds to the cost and self-weight of the bridge. In addition, this solution is not possible in the case of an existing structure.

4. Effect of a welded longitudinal stiffener on the flange

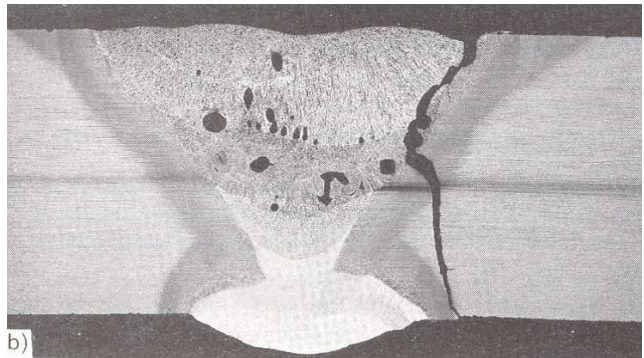
With a transverse or short longitudinal stiffener, we have seen that we have a detail category 80. If it is a thick transverse stiffener, $L > 50$ mm, it is one category lower.

If it is a long longitudinal stiffener, $L > 100$ mm, then the detail category can go down to 56!

PROBLEM 2



- a) Joint with transversal X weld.
Partial penetration, or lack of penetration.
Cracking from the root.
By analogy, equiv. to Table 8.3 detail 13, FAT36
OR ELSE, Table 8.5 detail 3, FAT36* with respect to the normal stress.
Note: not at all recommended for fatigue, and the lack of penetration should be limited, e.g. $< 50\%$ of the thickness, otherwise the fatigue strength may be less than FAT36 !
Must meet quality control standards (there is no detail category for a non-compliant weld).



- b) Joint with transversal V weld with reverse seam welding.
Contains pores, cracking from the weld toe, which shows an undercut, or possibly from pores.
If the pores meet quality control standards (nb of pores, max. dimensions), then cracking will occur from the weld toe.
Table 8.3 detail 11, overfill $< 20\%$, FAT80.
If pores do not meet quality control standards, then the weld must be repaired (there is no detail category for a non-compliant weld).