Rainflow Count of Cycles

For complicated stress histories it is non-trivial to count stress cycles in order to apply S-N diagrams. Hence, the problem addressed in this section is how to divide a complicated time-history into cycles, to count those cycles, and then to determine the damage, *D*. The adopted approach is referred to as the rainflow method, which can be interpreted in several ways. For example, by Masing's hypothesis it can be linked with hysteretic stress-strain curves, in which one rainflow cycle is one closed stress-strain hysteresis loop. Other interpretations are also possible.

It is an objective to count all cycles, small and large, including the large ones that are interrupted by small cycles. The rainflow method counts half-cycles, and every part of the time-history are associated with exactly one of the identified half-cycles. At each local peak or local valley, one half-cycle is ending and another is starting. Importantly, the peaks and valleys are paired so as to give the largest possible half cycle, going from the biggest possible to the next.

The rainflow method of counting cycles is visualized in Figure 1 for two sample time histories. It is first observed that the time histories are turned 90° to facilitate the rainflow analogy. As a result, the dashed lines in Figure 1 can be thought of as rainflows on a pagoda roof. The time-history in Figure 1a is periodic with constant amplitude. A quick count without any rainflow analogy reveals that it contains four full cycles. In contrast, there are eight rainflows that originate at each extreme. Each of these rainflows represents a half-cycle. As a result, half-cycle count by the rainflow method for the time-history in Figure 1a yields eight half-cycles. Four of the half-cycles are in tension, terminating with an arrow on the right side, and four are in compression, terminating with an arrow on the left side. In this case, all the half-cycles are of equal magnitude, hence the four tension-half-cycles can be added to the four compression-half-cycles to yield four full stress cycles, which is obviously the correct answer.

The time-history in Figure 1b is more complicated. According to the rainflow method, each compression half-cycle starts at a tension peak and ends when it meets a flow from above or when it falls all the way to the ground, so to speak. With that in mind, there are four compression half-cycles, named 1, 2, 3, and 4 in Figure 1b, and there are four tension half-cycles, named A, B, C, and D. The magnitude of each half cycle is the stress range that it has travelled, i.e., horizontal distance. In this case the half cycles are all of different magnitude, thus they cannot directly be added to obtain full cycles. It is often the case in rainflow analysis that some "spare" half-cycles remain after the half-cycles have been added to a number of full cycles.

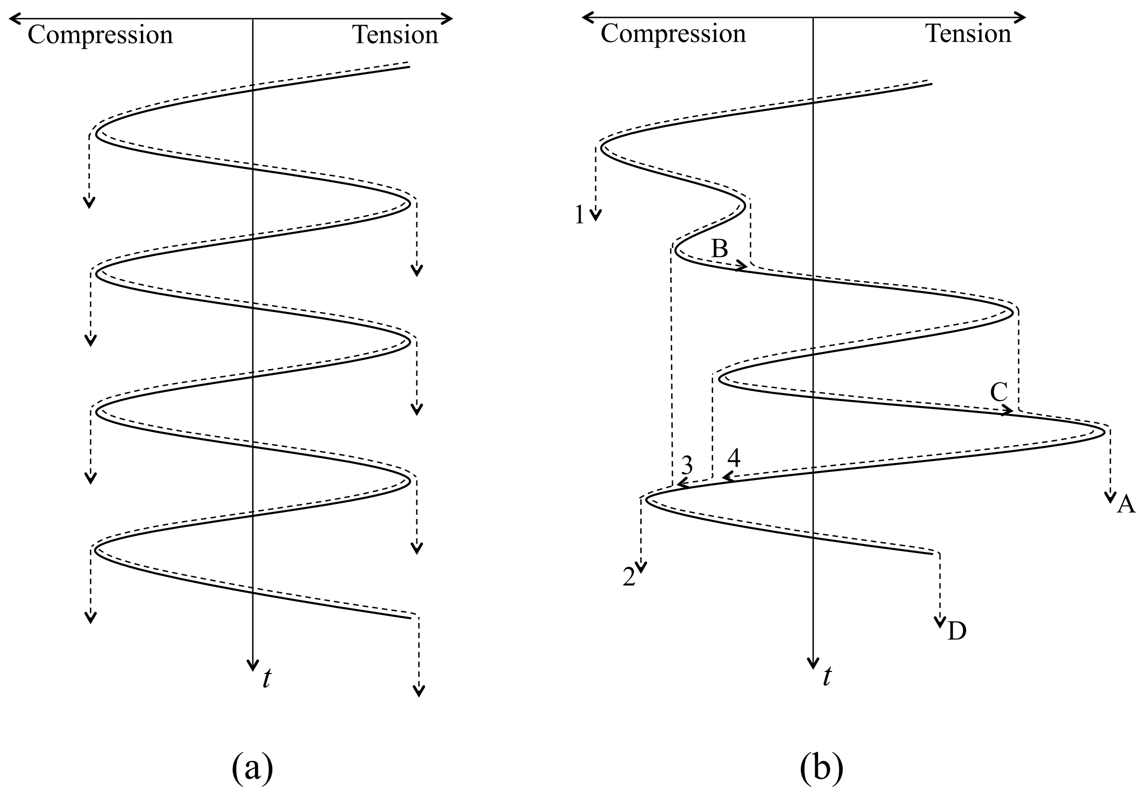

Figure 1: Counting half-cycles by the rainflow method.

Several algorithms exist for counting half-cycles by the rainflow method. An algorithm proposed by Downing and Socie in 1982 is particularly popular, and is provided in the following (Downing and Socie 1982; Lutes and Sarkani 1997). The algorithm starts by reorganizing the time-history slightly; the start-time is taken as the location of the highest peak, and the time-history that preceded that peak is moved to the end. Next, the amplitude of all the local peaks and valleys are collected in the vector **x**, obviously with the first element being largest because of the mentioned reorganization of the time-history. During the execution of the algorithm, a vector **q**, which varies in size, is also maintained. The algorithm is initialized by setting $q_1=x_1$, $q_2=x_2$, $q_3=x_3$, and $n=3$, and then repeats the following steps until there is no more data in **x**, i.e., until x_m is out of bounds:

1. Set range: $R_1=|q_n-q_{n-1}|$
2. Set previous adjacent range: $R_2=|q_{n-1}-q_{n-2}|$
3. If ($R_1<R_2$) then R_2 is NOT a rainflow range, so do the following:
    a. $n=n+1$
4. Else R_2 is a rainflow range and do the following:
    a. Register R_2 as a rainflow half-cycle
    b. Remove its two extrema q_{n-1} and q_{n-2} from **q**, i.e., shorten **q** by two
    c. $n=n-2$
    d. Append to **q** the next element of **x** if the size of **q** is less than three