RAINFLOW

VERIFICATION TEST CASES

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Case 1: In this case the cycles of a simple stress spectrum are re-sequenced using Rainflow algorithm. The aim of this test case is to check EXCEL based results with hand calculation.

Case 1 Problem Description:

The pre-rainflow stress spectrum is given in Table 5. Re-sequence the stress cycles using rainflow algorithm.

Table-5: Pre-rain flow stress spectrum

Event	σ_1	σ_2	Cycles
5	+456.96 MPa	-35.56 MPa	1
6	+531.77 MPa	+276.16 MPa	88
7	+415.50 MPa		1

Pre-rain flow stress vector (182 points):

$$\left\{\begin{array}{c} -35.56 \\ +456.96 \\ -35.56 \\ +415.50 \\ +531.77 \\ +276.16 \\ .... \\ .... \\ .... \\ +531.77 \\ +276.44 \\ +415.50 \\ +415.50 \end{array}\right\} \text{MPa}$$

Eliminated repeat cycles (86 cycles = 172 points):

Table-6: Eliminated repeat cycles

Event	σ_1	σ_2	Cycles
6	+531.77 MPa	+276.16 MPa	86

Pre-rain flow stress vector after removal of estimated repeated cycles (10 points):

$$\left\{\begin{array}{c} -35.56 \\ +456.96 \\ -35.56 \\ +415.50 \\ +531.77 \\ +276.16 \\ +531.77 \\ +276.16 \\ +415.50 \\ +415.50 \end{array}\right\} \text{MPa}$$

In the code, events with zero frequency are always associated with a steady stress (which in this case is 0.0 MPa for events other than 5, 6 and 7). Therefore, the actual pre-rainflow stress vector will have several 0.0 MPa stress points at the beginning (associated with events 1 through 4) and several 0.0 MPa stress points at the end (associated with event 8 through end).

$$\left\{\begin{array}{c} 0.0 \\ \ldots \\ 0.0 \\ -35.56 \\ +456.96 \\ -35.56 \\ +415.50 \\ +531.77 \\ +276.16 \\ +531.77 \\ +276.16 \\ +415.50 \\ +415.50 \\ 0.0 \\ \ldots \\ 0.0 \end{array}\right\} \text{MPa}$$

Re-arranged pre-rain flow stress vector with max value at start and end:

$$\left\{\begin{matrix} +531.77 \\ +276.16 \\ +531.77 \\ +276.16 \\ +415.50 \\ +415.50 \\ 0.0 \\ 0.0 \\ ... \\ ... \\ ... \\ -35.56 \\ +456.96 \\ -35.56 \\ +415.50 \\ +531.77 \end{matrix}\right\} \text{MPa}$$

Since cycles are associated with stress reversal, eliminate any stress point between a max stress point and a min stress point. Also, remove cycles (not stress point) with amplitude 0.0 MPa. The resultant pre-rainflow stress vector (9 points) is as follows:

$$\left\{\begin{matrix} +531.77 \\ +276.16 \\ +531.77 \\ +276.16 \\ +415.50 \\ -35.56 \\ +456.96 \\ -35.56 \\ +531.77 \end{matrix}\right\} \text{MPa}$$

Step-3: Compute post-rain flow stress spectrum.

Table-7 shows the extraction of cycles by rain flow algorithm from the 9-point pre-rain flow stress spectrum. Figures 1, 2 and 3 show the stress points before the start of any pass for extraction of cycles. Post rain-flow stress spectrum is shown in Table-8. Table-9 shows the calculation of equivalent stress by Airbus method.

Table-7: Rain flow stress cycle extraction based on 9 points

Point	Value	Pass 1		Pass 2		Pass 3	
		Status	Post-spec σ	Status	Post-spec σ	Status	Post-spec σ
a	531.77					remove	4-smax (full)
b	276.16			remove	3-smin (full)		
c	531.77			remove	3-smax (full)		
d	276.16	remove	1-smin (full)				
e	415.50	remove	1-smax (full)				
f	-35.56					remove	4-smax (full)
g	456.96	remove	2-smin (full)				
h	-35.56	remove	2-smax (full)				
a	531.77					remove	4-smax (full)

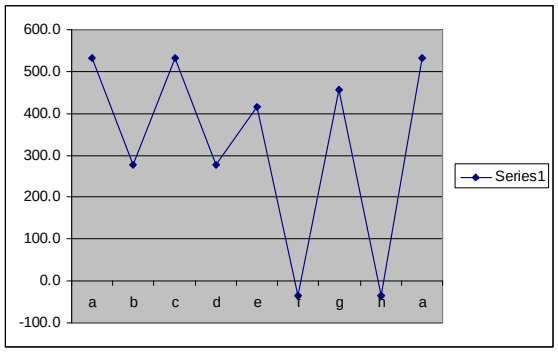

Figure-1: Pass 1 cycle extraction

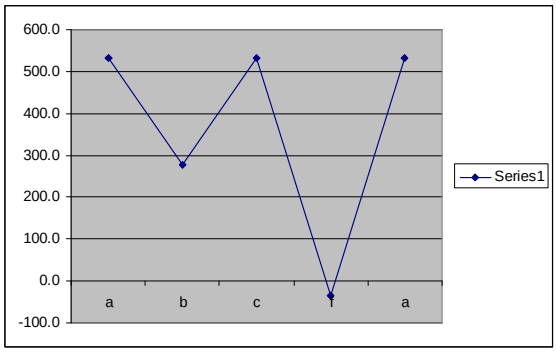

Figure-2: Pass 2 cycle extraction

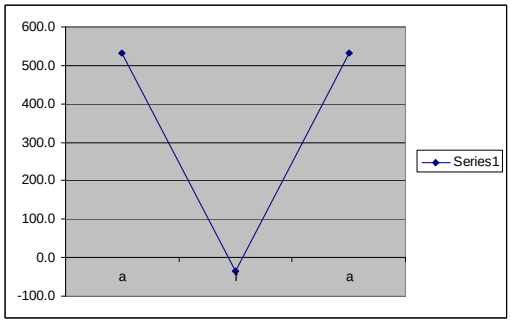

Figure-3: Pass 3 cycle extraction

Table-8: Post rain flow stress spectrum

From retained points			From eliminated points			Total		
σ_1(MPa)	σ_2(MPa)	cycles	σ_1(MPa)	σ_2(MPa)	cycles	σ_1(MPa)	σ_2(MPa)	cycles
415.50	276.16	1				415.50	276.16	1
456.96	-35.56	1				456.96	-35.56	1
531.77	276.16	1				531.77	276.16	1
531.77	-35.56	1				531.77	-35.56	1
			531.77	276.16	86	531.77	276.16	86

Case 2: The data for this problem is shown below and was provided by Jean-baptiste Cannes/ABF. Though 10 data points were provided, an eleventh data point was added as the algorithm requires the time history to start and end at maximum value.

Case 2 Problem Description:

Pre-rainflow		
Smax	Smin	Cycles
point 1	334	1
point 2	-197	1
point 3	324	1
point 4	-225	1
point 5	310	1
point 6	-213	1
point 7	297	1
point 8	-204	1
point 9	284	1
point 10	-194	1
point 11	334	1

***Results*:**

Post-rainflow		
Smax	Smin	Cycles
324	-197	1
284	-194	1
297	-204	1
310	-213	1
334	-225	1

EXCEL based MACRO results agree with hand calculations.

Case 3: The data for this problem is from the following web site.
http://www.me.fau.edu/~salivar/FailurePrevention.html

Case 3 Problem Description:

Pre-rainflow		
Smax	Smin	Cycles
point 1	70	1
point 2	-10	1
point 3	30	1
point 4	-50	1
point 5	50	1
point 6	0	1
point 7	60	1
point 8	-70	1
point 9	-10	1
point 10	-40	1
point 11	60	1
point 12	-90	1
point 13	40	1
point 14	-20	1
point 15	70	1

Results:

Post-rainflow		
Smax	Smin	Cycles
30	-10	1
50	0	1
-10	-40	1
40	-20	1
60	-50	1
60	-70	1
70	-90	1

The post-rain flow spectrum obtained by the MACRO code and shown above agrees with the histogram shown in reference.

Case 4: The data for this problem is from the following web site.
http://www.me.iastate.edu/me515_comer/Lecture/lecture25.pdf#search='rainflow%20lecture25'

Case 4 Problem Description:

Pre-rainflow		
Smax	Smin	Cycles
point 1	28	1
point 2	-18	1
point 3	8	1
point 4	2	1
point 5	22	1
point 6	-6	1
point 7	20	1
point 8	8	1
point 9	20	1
point 10	-18	1
point 11	22	1
point 12	-4	1
point 13	26	1
point 14	12	1
point 15	28	1

***Results*:**

Post-rainflow code			Post-rainflow reference		
Smax	Smin	Cycles	Smax	Smin	Cycles
8	2	1	8	2	1
20	8	1	20	8	1
22	**-18**	**1**	**22**	**-18**	**1**
22	-4	1	22	-4	1
26	12	1	26	12	1
20	**-6**	**1**	**20**	**-6**	**1**
28	-18	1	28	-18	1

The results are exactly as per reference.

Case 5: This problem is from "Standard Practices for Cycle Counting in fatigue Analysis", ASTM E 1049-85 (Re-approved 2005).

Case 5 Problem Description:

Pre-rainflow		
Point	Value	Cycles
point A	-2	1
point B	1	1
point C	-3	1
point D	5	1
point E	-1	1
point F	3	1
point G	-4	1
point H	4	1
point I	-2	1

***Results*:**

Post-rainflow		
Smax	Smin	Cycles
3	-1	1
1	-2	1
4	-3	1
5	-4	1

The results are exactly as per reference.

In reference a cycle (closed hysteresis loop) is one in which the range of a stress reversal is **less than** to one before and one after it. In the algorithm used in EXCEL based MACRO, a cycle (closed hysteresis loop) is one in which the range of a stress reversal is **less than or equal** to one before and one after it.

Case 6: This problem has largest point of vector as first or second point to show maximum or minimum points are not missed based on location.

Case 6 Problem Description:

Pre-rainflow		
Point	Value	Cycles
point A	.001	1
point B	-.006	1
point C	-.001	1
point D	.002	1
point E	-.001	1
point F	-.004	1
point G	-.001	1
point H	.001	1
point I	.001	1
point J	-.001	1
point K	.001	1
point L	-.001	1
point M	.001	1
point N	.001	1

Results:

Input vector size	14			
Event	t1(in)	t2(in)	t1(out)	t2(out)
1	0.001	-0.006	0.001	-0.001
2	-0.001	0.002	0.001	-0.001
3	-0.001	-0.004	0.001	-0.004
4	-0.001	0.001	0.002	-0.006
5	0.001	-0.001		
6	0.001	-0.001		
7	0.001	0.001		

The results agree with hand calculation.

Case 7: In this problem all points of vector are negative to show that cycles are correctly captured even if there is no zero crossing.

Case 7 Problem Description:

Pre-rainflow		
Point	Value	Cycles
point A	-.043	1
point B	-.048	1
point C	-8.763	1
point D	-10.377	1
point E	-8.763	1
point F	-0.057	1
point G	-8.763	1
point H	-9.915	1
point I	-.043	1
point J	-.055	1
point K	-7.680	1
point L	-.058	1
point M	-7.542	1
point N	-.043	1

***Results*:**

Input vector size	14			
Event	t1(in)	t2(in)	t1(out)	t2(out)
1	-0.043	-0.048	-0.057	-9.915
2	-8.763	-10.377	-0.043	-10.377
3	-8.763	-0.057	-0.058	-7.542
4	-8.763	-9.915	-0.043	-7.680
5	-0.043	-0.055		
6	-7.680	-0.058		
7	-7.542	-0.043		

The results agree with hand calculation.