OPTIMAT BLADES
RAINFLOW - EQL - BENCHMARKING

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NOTE: Green words indicate items to be completed by the person working on the document. Here: Please choose correct author and change character format!

1 Rainflow - EQL - Benchmarking

1.1 General

To verify the compatibility of the **RAINFLOW** counting algorithm and **EQ**uilvalent **L**oad determination technique of the partners participating in TG1 WP 4 *NEW WISPER* a benchmark exercise is carried out. A sample supplied by DEWI is evaluated and is characterized as follows:

- sample data set of 30000 data points i.e. 600s duration and a sample rate of 50 Hz as typically recorded during load measurements (data set name: ***600sTH***)

In the described exercise the sample data set is to be processed by the Rainflow counting software routine as used by each partner's commercial services:

- ***DEWI:*** IMC COM Software Package COM/Klass-D V.1 Rev. 4 used in evaluation procedures for time series measurements. This software uses Rainflow counting according to ASTM E1049-85 (reapproved 1990), *Standard Analysis*.

- ***CRES:*** *The algorithm used is described in IEA "Recommended practices for wind turbine testing and evaluation; 3 Fatigue loads" (Edition 1990), following IEC 61400-13 "Measurement of Mechanical Loads" (Edition 1998).*
  Since the algorithm is half-cycle counting the sample data (in particular the residuals after the range pair extraction), sequence is to be Rainflow counted and the result shall be presented in half cycle matrices as well as range spectra. 1-Hz-EQL values are to be derived.

- ***ECN:*** *to be completed*

The sample data sequence is to be Rainflow counted and the result shall be presented in a full cycle matrices as well as range-pair spectra. From the range pair spectra the 1-Hz-EQL values are to be derived. Range pair spectra and EQLs are grouped in an Excel sheet for ready access.

1.2 Sample Data

In the following the sample data are represented.

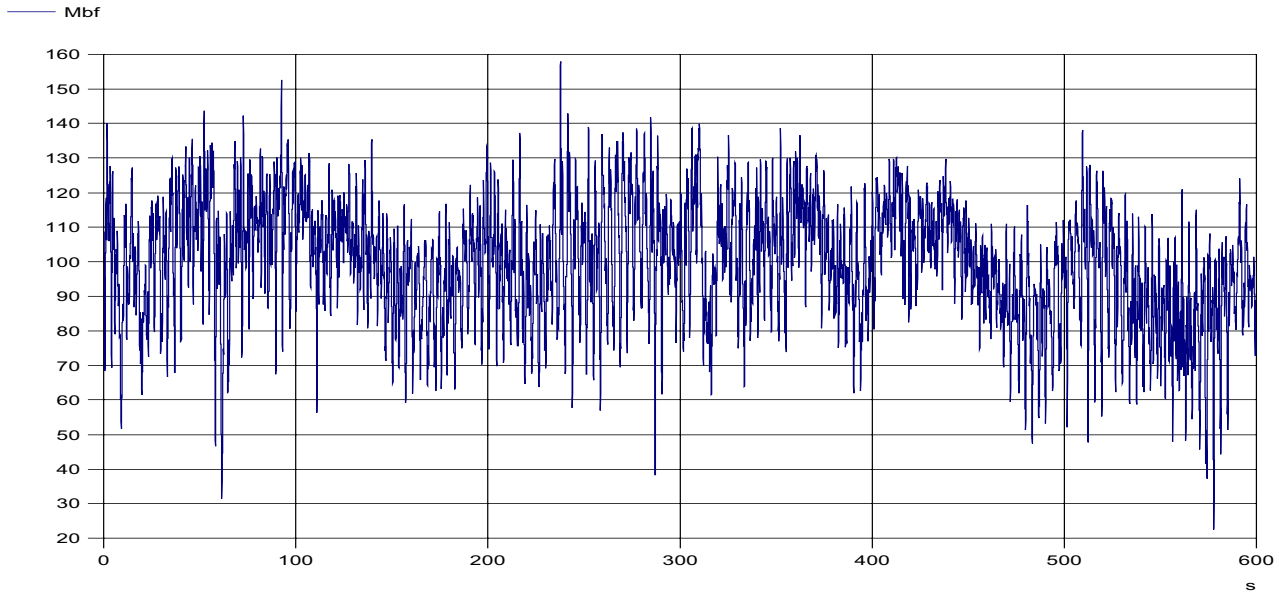

Fig. 1. Sample Time History *600sTH*

1.3 Rainflow Counting Parameters

To perform the rainflow count on the sample data parameters are set to:

RAINFLOW COUNTING PARAMETERS	600sTH
No of Bins, evenly devided	64
Full Scale Minimum	0
Full Scale Maximum	200
Hysteresis (110% of Bin Width)	3.4375
Treatment of Residuals 1 = each residual transition from one load level to another is added as a full cycle to the rain flow full cycle matrix 0 = residual transition from one load level to another are neglected	1

Tab. 1. Rainflow Counting Parameter *600sHT*

RAINFLOW COUNTING PARAMETERS for CRES	600sTH
No of Bins, evenly divided	64
Full Scale Minimum	0
Full Scale Maximum	200
Threshold (5% of Bin Width)	0.15625
Treatment of Residuals 1 = each residual transition from one load level to another is counted as a half cycle to the rain flow full cycle matrix 0 = residual transition from one load level to another are neglected	1

Tab. 2. Rainflow Counting Parameter *600sTH used by CRES*

1.4 Equivalent Load Parameters

To compute the equivalent load from the Rainflow range pair spectra the following parameters are specified:

EQUIVALENT LOAD PARAMETERS	600sHT
No of Bins (i)	64
N_{ref} = Number of equivalent load cycles	600
M = material exponent	3, 4, 6, 8, 10, 12
Formula used	$L_{eq} = \left(\frac{\sum n_i * L_i^m}{N_{ref}} \right)^{(1/m)}$

Tab. 3. Equivalent Load Parameter *600sHT*

EQUIVALENT LOAD PARAMETERS used by CRES	600sTH
No of Bins (i)	64
N_{ref} = Number of equivalent load cycles	600
m = material exponent	3, 4, 6, 8, 10, 12
Formula used where L_i is taken as the upper bound of each bin	$L_{eq} = \left(\frac{\sum n_i L_i^m}{2N_{ref}} \right)^{1/m}$

Tab. 4. Equivalent Load Parameter *600sTH*

For the material constant values of 3, 4, 6, 8, 10, 12 are to be evaluated. The number of equivalent load cycles is assumed to be 600. As the test sequence has a total duration of 600 seconds the computed EQL corresponds to the 1Hz-EQL.

1.5 Results

The results of the benchmark exercise are presented in the following.

1.5.1 Results From DEWI

In the appendix DEWI's Rainflow full cycle matrix in *Range-Mean* representation is listed in tabular format. It has been obtained by using the IMC COM Software Package COM/Klass-D V.1 Rev. 4. The matrix data include the residual counts. Table 5 gives the range pair spectrum obtained from the Rainflow matrix:

Range Pair Spectrum		*600sTH*	
Bin	Load in i-th Bin	Cumulative frequency	counts
1	1.5625	622	0
2	4.6875	622	83
3	7.8125	539	120
4	10.9375	419	72
5	14.0625	347	61
6	17.1875	286	41
7	20.3125	245	29
8	23.4375	216	24
9	26.5625	192	23
10	29.6875	169	20
11	32.8125	149	11
12	35.9375	138	11
13	39.0625	127	9
14	42.1875	118	16
15	45.3125	102	12
16	48.4375	90	13
17	51.5625	77	13
18	54.6875	64	16
19	57.8125	48	9
20	60.9375	39	3
21	64.0625	36	9
22	67.1875	27	5
23	70.3125	22	3
24	73.4375	19	5
25	76.5625	14	3
26	79.6875	11	3
27	82.8125	8	1
28	85.9375	7	1
29	89.0625	6	1
30	92.1875	5	1
31	95.3125	4	1
32	98.4375	3	0
33	101.5625	3	1
34	104.6875	2	0
35	107.8125	2	0
36	110.9375	2	1
37	114.0625	1	0
38	117.1875	1	0
39	120.3125	1	0
40	123.4375	1	0
41	126.5625	1	0
42	129.6875	1	0
43	132.8125	1	0
44	135.9375	1	1
45	139.0625	0	0
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64	198.4375	0	0

Table 5: DEWI Range-Pair Spectrum

Figure 3 depicts the range pair spectrum (cumulative frequency of counted rainflow cycles) as obtained by using the IMC COM Software Package COM/Klass-D V.1 Rev. 4.

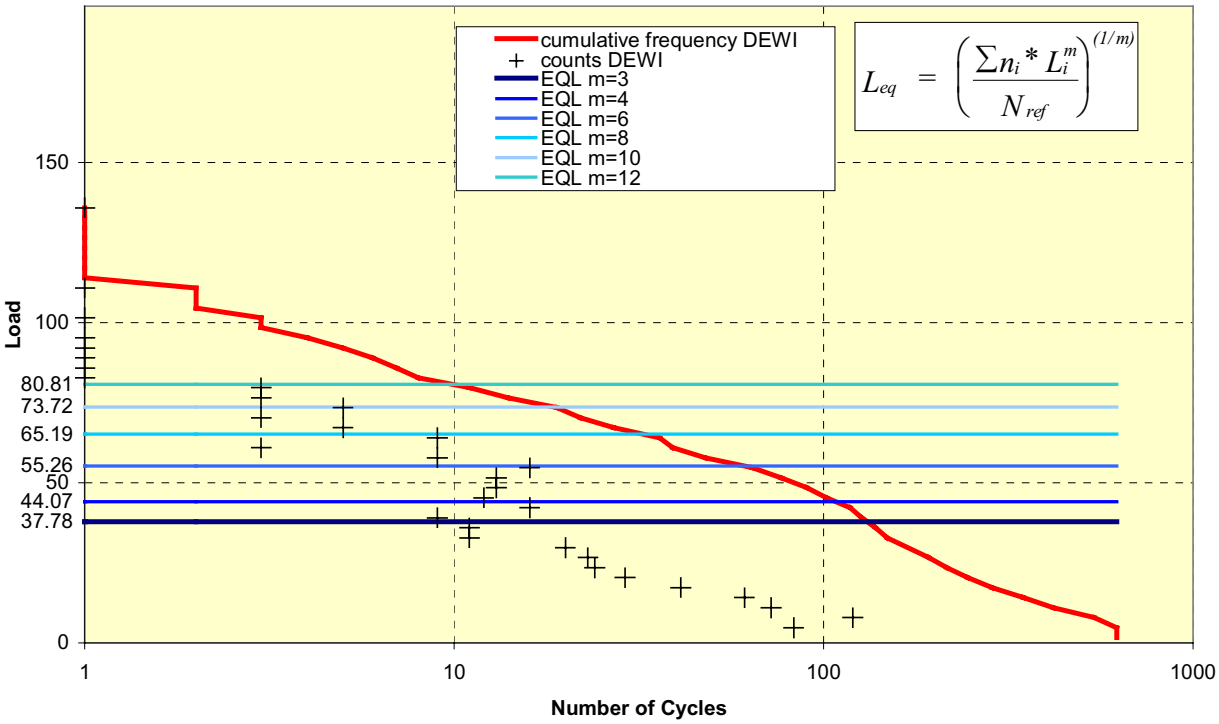

Fig. 3: DEWI's Range-Pair Spectrum and 1-Hz EQL of Test Sequence ***600sTH***

material exponent m	3	4	6	8	10	12
equiv. No. of cycles	600	600	600	600	600	600
EQL	37.7764	44.0705	55.2593	65.1864	73.7215	80.8146

Table 6: DEWI'S 1Hz-EQL Results

1.5.2 Results From CRES

Following table (Table 7) gives the range spectrum obtained from the Rainflow matrix. The matrix data includes the residual counts. Rainflow counting matrix has been obtained by an in-house built software using the algorithm described in previous section of this document. In the appendix CRES' rainflow half cycle matrix in Range – Mean representation is listed in tabular format.

Range Pair Spectrum	600sTH		
Bin	Load in i-th Bin	Cumulative frequency	half cycle counts
1	1.5625	4164	2851
2	4.6875	1313	376
3	7.8125	937	184
4	10.9375	753	138
5	14.0625	615	92
6	17.1875	523	64
7	20.3125	459	50
8	23.4375	409	50
9	26.5625	359	44
10	29.6875	315	26
11	32.8125	289	24
12	35.9375	265	12
13	39.0625	253	31
14	42.1875	222	32
15	45.3125	190	26
16	48.4375	164	24
17	51.5625	140	33
18	54.6875	107	22
19	57.8125	85	8
20	60.9375	77	14
21	64.0625	63	12
22	67.1875	51	12
23	70.3125	39	5
24	73.4375	34	10
25	76.5625	24	6
26	79.6875	18	2
27	82.8125	16	2
28	85.9375	14	2
29	89.0625	12	1
30	92.1875	11	3
31	95.3125	8	2
32	98.4375	6	0
33	101.5625	6	3
34	104.6875	3	0
35	107.8125	3	0
36	110.9375	3	1
37	114.0625	2	0
38	117.1875	2	0
39	120.3125	2	0
40	123.4375	2	0
41	126.5625	2	1
42	129.6875	1	0
43	132.8125	1	0
44	135.9375	1	1
45	139.0625	0	0
--	--		
64	198.4375	0	0

Table 7: CRES Range Spectrum

Figure 4 depicts the range spectrum (cumulative frequency of counted rainflow half cycles) as obtained by using an software built by CRES using the algorithm described in previous section of this document.

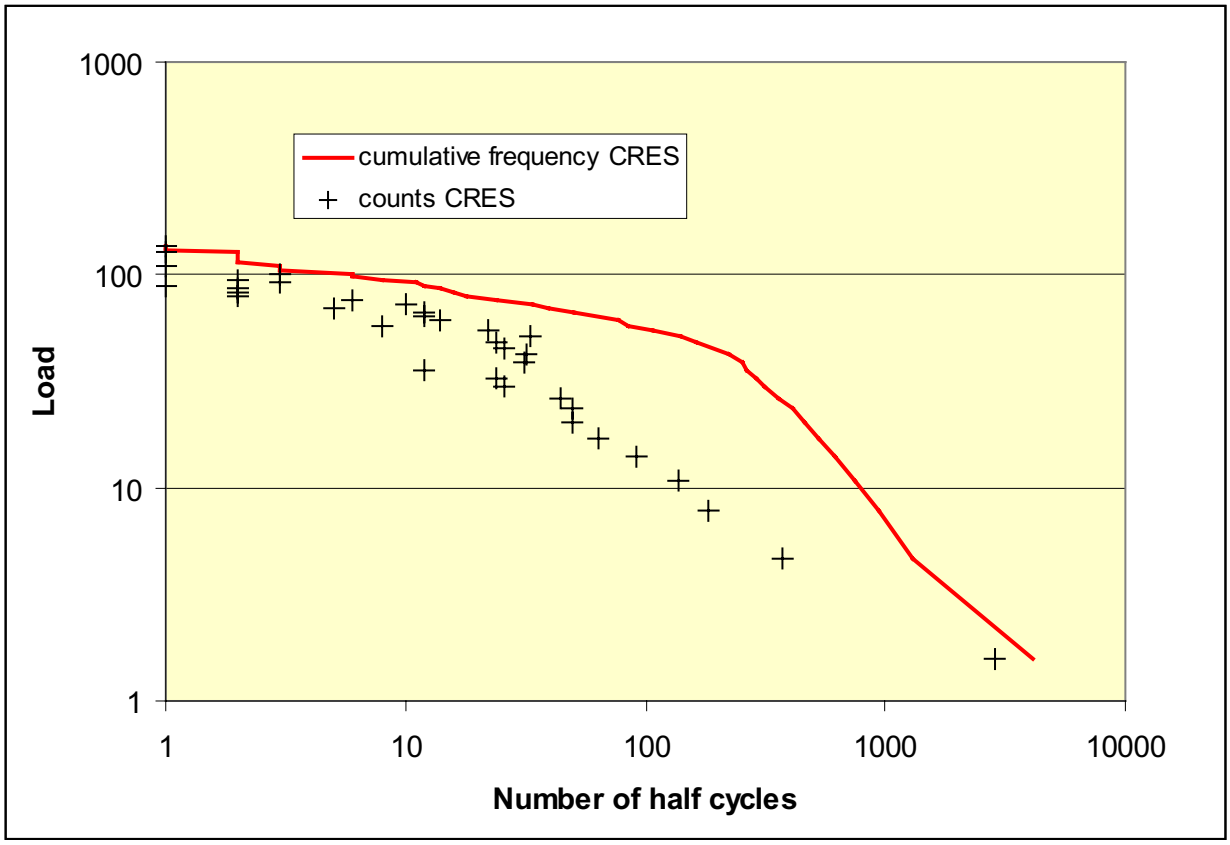

Fig. 4: CRES' Range Spectrum and 1-Hz EQL of Test Sequence ***600sTH***

Material exponent m	3	4	6	8	10	12
Equiv. No. of cycles	600	600	600	600	600	600
EQL	37.7863	44.0165	54.9663	64.5422	72.7771	79.6827

Table 8: CRES 1Hz- EQL Results

1.5.3 Results From ECN

In the appendix ECN's Rainflow full cycle matrix in Range-Mean representation is listed in tabular format. It has been obtained by using XXXX Software Package. The matrix data include the residual counts. Table 9 gives the range pair spectrum obtained from the Rainflow matrix:

Range Pair Spectrum	600sTH		
Bin	Load in i-th Bin	Cumulative frequency	counts
1	1.5625		
2	4.6875		
3	7.8125		
4	10.9375		
5	14.0625		
6	17.1875		
7	20.3125		
8	23.4375		
9	26.5625		
10	29.6875		
11	32.8125		
12	35.9375		
13	39.0625		
14	42.1875		
15	45.3125		
16	48.4375		
17	51.5625		
18	54.6875		
19	57.8125		
20	60.9375		
21	64.0625		
22	67.1875		
23	70.3125		
24	73.4375		
25	76.5625		
26	79.6875		
27	82.8125		
28	85.9375		
29	89.0625		
30	92.1875		
31	95.3125		
32	98.4375		
33	101.5625		
34	104.6875		
35	107.8125		
36	110.9375		
37	114.0625		
38	117.1875		
39	120.3125		
40	123.4375		
41	126.5625		
42	129.6875		
43	132.8125		
44	135.9375		
45	139.0625		
--	--		
64	198.4375		

Table 9: ECN Range-Pair Spectrum

Figure 5 depicts the range pair spectrum (cumulative frequency of counted rainflow cycles) as obtained by using the XXXXSoftware Package.

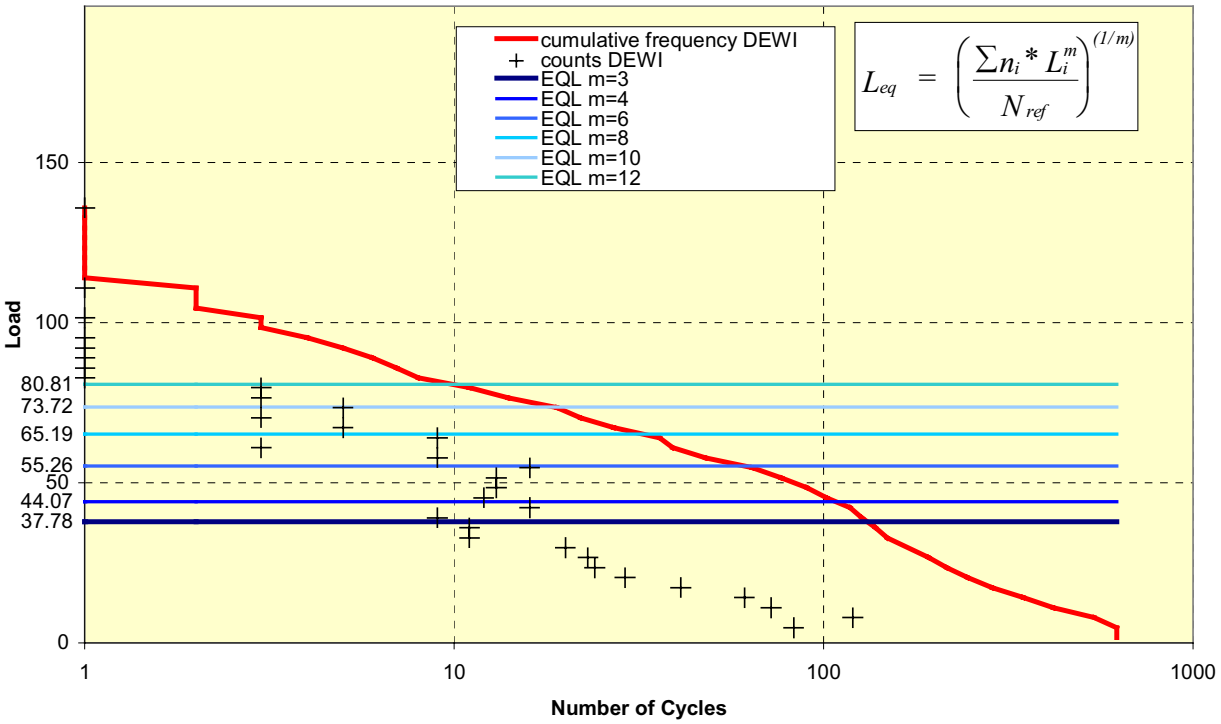

*Fig. 5: ECN Range-Pair Spectrum and 1-Hz EQL of Test Sequence **600sTH***

material exponent m	*3*	*4*	*6*	*8*	*10*	*12*
equiv. No. of cycles	*600*	*600*	*600*	*600*	*600*	*600*
EQL						

Table 9: ECN 1Hz- EQL Results

1.6 Conclusion

TO BE COMPLETED

1.7 CONTACT

In case of questions or support is needed turn to

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2 APPENDIX

2.1 DEWI's Results

Range Mean Matrix (Tabular Format) 600sTH		
No of Bins, evenly devided		64
Full Scale Minimum		0
Full Scale Maximum		200
Hysteresis (110% of Bin Width)		3.4375
Treatment of Residuals 1 = each residual transition from one load level to another is added as a full cycle to the rain flow full cycle matrix 0 = residual transition from one load level to another are neglected		
range	mean	no of cycles
2	20	1
2	23	2
2	24	2
2	25	1
2	26	1
2	27	2
2	28	4
2	29	5
2	30	4
2	31	9
2	32	5
2	33	7
2	34	14
2	35	7
2	36	4
2	37	6
2	38	2
2	39	4
2	40	1
2	41	1
2	42	1
3	24	2
3	25	2
3	26	4
3	27	6
3	28	9
3	29	7
3	30	7
3	31	6
3	32	12
3	33	9
3	34	10
3	35	6
3	36	10
3	37	8
3	38	6
3	39	6

3	40	5
3	41	3
3	42	2
4	15	1
4	23	1
4	24	1
4	25	1
4	26	5
4	27	3
4	28	7
4	29	2
4	30	2
4	31	5
4	32	6
4	33	6
4	34	5
4	35	10
4	36	3
4	37	7
4	38	3
4	39	3
4	40	1
5	23	1
5	25	3
5	26	1
5	27	4
5	28	1
5	29	2
5	30	5
5	31	4
5	32	4
5	33	3
5	34	7
5	35	5
5	36	8
5	37	5
5	38	3
5	39	4
5	41	1
6	25	1
6	27	2
6	28	5
6	29	4
6	30	3
6	31	3
6	32	2
6	33	6
6	34	4
6	35	2
6	36	2
6	37	2
6	38	1
6	39	3

6	40	1
7	26	2
7	27	1
7	30	1
7	31	1
7	32	4
7	33	3
7	34	5
7	35	5
7	36	3
7	37	2
7	40	2
8	25	1
8	28	2
8	29	4
8	30	3
8	31	1
8	33	2
8	34	1
8	35	2
8	36	2
8	37	3
8	38	3
9	26	2
9	27	1
9	28	2
9	29	1
9	30	2
9	31	1
9	32	6
9	33	2
9	34	1
9	35	1
9	37	3
9	38	1
10	25	1
10	27	2
10	28	1
10	30	1
10	31	1
10	33	4
10	34	1
10	35	2
10	36	5
10	37	2
11	26	1
11	28	1
11	29	1
11	30	1
11	33	1
11	35	1
11	36	1
11	37	4

12	30	1
12	31	1
12	32	3
12	33	2
12	35	1
12	36	2
12	37	1
13	24	1
13	28	1
13	30	1
13	31	1
13	32	2
13	34	1
13	35	1
13	36	1
14	27	1
14	28	1
14	29	3
14	31	5
14	32	1
14	35	3
14	36	1
14	38	1
15	28	3
15	29	2
15	30	1
15	31	1
15	32	2
15	35	3
16	27	2
16	28	1
16	29	1
16	31	2
16	32	2
16	33	1
16	34	4
17	26	1
17	28	2
17	29	2
17	33	3
17	34	2
17	35	1
17	36	2
18	28	2
18	29	4
18	30	1
18	31	2
18	33	4
18	34	2
18	35	1
19	24	1
19	26	1
19	27	1

19	28	2
19	31	1
19	32	1
19	33	1
19	34	1
20	24	1
20	26	1
20	29	1
21	32	3
21	33	1
21	34	4
21	35	1
22	26	1
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22	33	1
22	34	1
23	26	1
23	30	1
23	31	1
24	23	1
24	27	1
24	29	1
24	32	2
25	32	1
25	34	2
26	28	1
26	31	1
26	32	1
27	32	1
28	32	1
29	31	1
30	30	1
31	34	1
33	29	1
36	28	1
44	29	1

Range Pair Spectrum		*600sTH*	
Bin	Load in i-th Bin	Cumulative frequency	counts
1	1.5625	622	0
2	4.6875	622	83
3	7.8125	539	120
4	10.9375	419	72
5	14.0625	347	61
6	17.1875	286	41
7	20.3125	245	29
8	23.4375	216	24
9	26.5625	192	23
10	29.6875	169	20
11	32.8125	149	11

12	35.9375	138	11
13	39.0625	127	9
14	42.1875	118	16
15	45.3125	102	12
16	48.4375	90	13
17	51.5625	77	13
18	54.6875	64	16
19	57.8125	48	9
20	60.9375	39	3
21	64.0625	36	9
22	67.1875	27	5
23	70.3125	22	3
24	73.4375	19	5
25	76.5625	14	3
26	79.6875	11	3
27	82.8125	8	1
28	85.9375	7	1
29	89.0625	6	1
30	92.1875	5	1
31	95.3125	4	1
32	98.4375	3	0
33	101.5625	3	1
34	104.6875	2	0
35	107.8125	2	0
36	110.9375	2	1
37	114.0625	1	0
38	117.1875	1	0
39	120.3125	1	0
40	123.4375	1	0
41	126.5625	1	0
42	129.6875	1	0
43	132.8125	1	0
44	135.9375	1	1
45	139.0625	0	0
46	142.1875	0	0
47	145.3125	0	0
48	148.4375	0	0
49	151.5625	0	0
50	154.6875	0	0
51	157.8125	0	0
52	160.9375	0	0
53	164.0625	0	0
54	167.1875	0	0
55	170.3125	0	0
56	173.4375	0	0
57	176.5625	0	0
58	179.6875	0	0
59	182.8125	0	0
60	185.9375	0	0
61	189.0625	0	0
62	192.1875	0	0
63	195.3125	0	0
64	198.4375	0	0

Table 4: DEWI Range-Pair Spectrum

2.2 CRES's Results

Range Mean Matrix (Tabular Format)		600sTH
No of Bins, evenly devided	64	
Full Scale Minimum	0	
Full Scale Maximum	200	
Threshold (5% of Bin Width)	0.15625	
Treatment of Residuals 1 = each residual transition from one load level to another is counted as a half cycle to the rain flow full cycle matrix		
range	mean	no of half cycles
1	13	2
1	14	2
1	16	2
1	18	6
1	20	18
1	21	22
1	22	30
1	23	36
1	24	51
1	25	80
1	26	90
1	27	118
1	28	130
1	29	116
1	30	154
1	31	182
1	32	196
1	33	204
1	34	220
1	35	236
1	36	222
1	37	208
1	38	186
1	39	92
1	40	104
1	41	56
1	42	40
1	43	28
1	44	6
1	45	12
1	46	2
2	21	2
2	23	2
2	24	10
2	26	10
2	27	22
2	28	12
2	29	30

2	30	8
2	31	32
2	32	40
2	33	24
2	34	38
2	35	34
2	36	26
2	37	30
2	38	10
2	39	18
2	40	16
2	41	6
2	42	4
2	43	2
3	24	4
3	25	6
3	26	4
3	27	8
3	28	16
3	29	10
3	30	12
3	31	10
3	32	16
3	33	22
3	34	12
3	35	18
3	36	12
3	37	14
3	38	6
3	39	8
3	40	4
3	41	2
4	15	2
4	23	2
4	24	2
4	25	4
4	26	4
4	27	12
4	28	6
4	29	2
4	30	8
4	31	6
4	32	6
4	33	12
4	34	10
4	35	10
4	36	18
4	37	10
4	38	10
4	39	8
4	40	2
4	41	4

5	25	2
5	28	8
5	29	6
5	30	12
5	31	4
5	32	6
5	33	2
5	34	16
5	35	14
5	36	6
5	37	6
5	38	4
5	39	4
5	41	2
6	25	2
6	26	2
6	28	2
6	29	6
6	30	2
6	31	6
6	32	4
6	33	4
6	34	10
6	35	4
6	36	6
6	37	6
6	39	4
6	40	6
7	26	2
7	27	2
7	28	2
7	30	6
7	31	2
7	32	6
7	33	6
7	34	6
7	35	6
7	36	2
7	37	6
7	38	4
8	26	4
8	29	6
8	30	8
8	31	4
8	32	4
8	33	2
8	34	4
8	35	4
8	37	6
8	38	6
8	39	2
9	26	2

9	27	2
9	28	10
9	32	8
9	33	4
9	34	6
9	35	2
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9	37	2
9	38	2
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10	30	2
10	31	4
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11	34	2
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11	36	2
11	37	6
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12	32	4
12	35	2
12	36	2
12	37	2
13	24	2
13	28	2
13	29	1
13	31	6
13	32	6
13	33	2
13	34	2
13	35	4
13	36	4
13	39	2
14	27	2
14	28	6
14	29	8
14	30	2
14	31	2
14	32	4
14	35	6
14	37	2
15	27	2
15	28	4
15	29	2
15	31	6
15	32	4
15	34	4

15	35	4
16	28	2
16	29	2
16	30	2
16	32	2
16	33	4
16	34	8
16	35	2
16	36	2
17	26	2
17	28	4
17	29	8
17	30	4
17	31	2
17	32	1
17	33	4
17	34	4
17	35	2
17	36	2
18	24	2
18	26	2
18	28	4
18	29	4
18	32	2
18	33	4
18	34	2
18	35	2
19	27	2
19	30	2
19	32	2
19	34	2
20	24	2
20	27	2
20	32	4
20	34	4
20	35	2
21	27	2
21	32	2
21	33	2
21	34	6
22	26	2
22	27	2
22	30	2
22	31	4
22	34	2
23	24	2
23	30	2
23	34	1
24	28	2
24	32	2
24	33	4
24	34	2

25	32	2
25	33	2
25	34	2
26	29	2
27	32	2
28	32	2
29	31	1
30	30	2
30	32	1
31	34	2
33	24	1
33	29	2
36	29	1
41	31	1
44	29	1

Range Spectrum ***600sTH***

Bin	Load in i-th Bin	Cumulative frequency	Half cycle counts
1	1.5625	4164	2851
2	4.6875	1313	376
3	7.8125	937	184
4	10.9375	753	138
5	14.0625	615	92
6	17.1875	523	64
7	20.3125	459	50
8	23.4375	409	50
9	26.5625	359	44
10	29.6875	315	26
11	32.8125	289	24
12	35.9375	265	12
13	39.0625	253	31
14	42.1875	222	32
15	45.3125	190	26
16	48.4375	164	24
17	51.5625	140	33
18	54.6875	107	22
19	57.8125	85	8
20	60.9375	77	14
21	64.0625	63	12
22	67.1875	51	12
23	70.3125	39	5
24	73.4375	34	10
25	76.5625	24	6
26	79.6875	18	2
27	82.8125	16	2
28	85.9375	14	2
29	89.0625	12	1
30	92.1875	11	3
31	95.3125	8	2
32	98.4375	6	0
33	101.5625	6	3

34	104.6875	3	0
35	107.8125	3	0
36	110.9375	3	1
37	114.0625	2	0
38	117.1875	2	0
39	120.3125	2	0
40	123.4375	2	0
41	126.5625	2	1
42	129.6875	1	0
43	132.8125	1	0
44	135.9375	1	1
45	139.0625	0	0
46	142.1875	0	0
47	145.3125	0	0
48	148.4375	0	0
49	151.5625	0	0
50	154.6875	0	0
51	157.8125	0	0
52	160.9375	0	0
53	164.0625	0	0
54	167.1875	0	0
55	170.3125	0	0
56	173.4375	0	0
57	176.5625	0	0
58	179.6875	0	0
59	182.8125	0	0
60	185.9375	0	0
61	189.0625	0	0
62	192.1875	0	0
63	195.3125	0	0
64	198.4375	0	0

2.3 ECN's Results