OPTIMAT BLADES
NEW WISPER RANGE PAIR- BENCHMARKING

2nd round

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1 NEW WISPER Range Pair - Benchmarking

1.1 General

To verify the compatibility of the **Annual-Range-Pair** and **Low-Cycle-Fatique** derivation technique of the partners participating in TG1 WP 4 *NEW WISPER* a benchmark exercise is carried out. Sample data supplied by DEWI are evaluated on the basis of:

- Bernard Bulder - ECN, Denja Lekou, Pantelis Vionis, Frangiskos Mouzakis - CRES, Rogier P.L. Nijssen - TUDelft, Theo Kramkowski, Holger Söker - DEWI: SYNTHESIS PROCESS OF A NEW WISPER LOAD SPECTRUM. DEWI, 27.10.2003, Wilhelmshaven

In the described benchmark exercise the sample data set is to be processed using the above mentioned synthesis procedure. In this procedure Rainflow counting is applied on the data. The participating partners are requested to specify the software routines :

- ***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:*** CRES in house developed software is used in evaluation for time series measurements. The software uses Rainflow counting algorithm as 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 is usually presented in half cycle matrices as well as range spectra. However, due to the fact that the rest of the participating institutes use a full cycle count all CRES results have been divided by the factor of two so as to be presented in full cycle matrices as well as range spectra.
- ***ECN:*** In house developed software Rainflow and Rainmtrx. Rainflow performes rainflow counting of time series according to *Recommended practices for wind turbine testing and evaluation; 3. Fatigue* . In Rainmtrx the range mean matrix and the range spectra are generated using the Rainflow results as input.

The annual Range Pair is to be derived from sample data and extrapolated to one year following the above quoted procedure and bullet 1.4. Subsequently normalisation of cyclic content (rotational speed) shall be carried out evaluating the number of cumulated rotor revolutions from the edgewise range pair spectrum. The number of revolutions is to be taken from the bin in which the second derivation of the range pair spectrum envelope is zero (approached from large loads to small loads). The normalization factor is found by relating the reference no of revolutions to the counted number of revolutions per year:

factor = ref. no. of revolutions / no of counted revolutions

As last step in this benchmark the Low-Cycle-Fatique values are be added as described in the “A simple approximative procedcure for taking into account low cycle fatique loads” by G.Larsen and K.Thomsen Ris∅ National Laboratory, Roskilde, Denmark January 1996.
The result shall be presented in a full cycle flatwise matrix as well as a flatwise range-pair spectrum. From the range pair spectrum the 1-Hz-EQL value are to be derived. Range pair spectra and EQLs are to be grouped in an Excel sheet for ready access.

1.2 Sample Data

The sample data are characterized as follows:

- data files (edge- and flatwise bending) for 12% turbulence intensity are sorted in wind bins from V03 (3m/s) up to V25 (25m/s) (normalized data!)
- a single start and stop data file are given in corresponding directories
- each sample data set contains 30000 data points i.e. 600s duration at sample rate of 50 Hz as typically recorded during load measurements

1.3 Rainflow Counting Parameters

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

RAINFLOW COUNTING PARAMETERS	edgewise
No of Bins, evenly devided	64
Full Scale Minimum	-2
Full Scale Maximum	2
Hysteresis (110% of Bin Width)	0.0688
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 *edgewise*

RAINFLOW COUNTING PARAMETERS	flatwise
No of Bins, evenly devided	64
Full Scale Minimum	-2
Full Scale Maximum	6
Hysteresis (110% of Bin Width)	0.1375
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. 2. Rainflow Counting Parameter *flatwise*

1.4 Range Pair Spectrum Parameters

To compute the annual range pair spectrum the following parameters are specified:

ANNUAL RANGE PAIR PARAMETERS	
Weibull Parameters	A= 9.59 C= 2.0
V_cut in	3 m/s
V_cut out	22 m/s
Low Cycle Fatigue considered	yes

Tab. 3. Annual Range Pair Parameter

For the low cycle fatigue portion the delivered annual wind speed time series is to be evaluated according to

- Larsen, G.; Thomsen, K.: A simple approximative procedure for taking into account low cycle fatigue loads. Paper presented at IEA-Symposium on Wind Turbine Fatigue, Stuttgart, February 1-2, 1996

The used numbers of starts and stops or transients at Cut-in and Cut-out wind speed are to be reported:

Definitions:

- start at cut in: whenever the 10-min-average wind speed chages from below 3m/s to above 3m/s
- start at cut out: whenever the 10-min-average wind speed chages from above 22m/s to below 22m/s
- stop at cut in: whenever the 10-min-average wind speed chages from above 3m/s to below 3m/s
- stop at cut out: whenever the 10-min-average wind speed chages from below 22m/s to above 22m/s

1.5 Equivalent Load Parameters

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

EQUIVALENT LOAD PARAMETERS DEWI	
No of Bins (i)	64
N_{ref} = Number of equivalent load cycles	31536000
M = material exponent	10
Formula used where L_i is taken as the mean of each bin	$L_{eq} = \left(\frac{\sum n_i * L_i^m}{N_{ref}} \right)^{(1/m)}$

Tab. 4a. Equivalent Load Parameter

EQUIVALENT LOAD PARAMETERS used by CRES	
No of Bins (i)	64
N_{ref} = Number of equivalent load cycles	31536000
m = material exponent	10
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. 4b. Equivalent Load Parameter *used for CRES*

EQUIVALENT LOAD PARAMETERS used by ECN	
No of Bins (i)	64
N_{ref} = Number of equivalent load cycles	25912901
M = material exponent	10
Formula used	$L_{eq} = \left(\frac{\sum n_i * L_i^m}{N_{ref}} \right)^{(1/m)}$

Tab. 4c. Equivalent Load Parameter *used for ECN*

For the material constant a value of 10 shall be evaluated. The number of equivalent load cycles is assumed to be 31536000. As the spectra represent a total of 1 one year the computed EQL corresponds to the 1Hz-EQL.

1.6 Overall Results

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

STATISTICS OF STARTS AND STOPS ACCORDING TO LCF				
	CRES	**DEWI**	**ECN**	
Starts cut-in	404	404	404	
Starts cut-out	17	17	17	
Stops cut-in	404	404	404	
Stops cut-out	17	17	17	
	level crossing analysis, no hysteresis applied	level crossing analysis, no hysteresis applied	level crossing analysis, no hysteresis applied	

Table 5: Statistics of starts and stops according to annual wind speed time history

NORMALIZATION OF CYCLIC CONTENT						
ref. Rpm	20					
min/year	525600					
ref. No. of rev.	10512000					
	DEWI	ECN	CRES			
Bin	30		28			
Counts	8376277.8	8642900	8276911			
mean rpm	15.936602	16.444	15.700195			
Factor	**1.2549727**	**1.217**	**1.2700389**			
Note! The normalization factor is to be carried out before adding the LCF-cycles !						

Table 6: NORMALIZATION OF CYCLIC CONTENT

Partner	CRES	CRES computed by DEWI	DEWI	ECN	ECN-computed by DEWI
Material exponent	10	10	10	10	10
EQL	1.748	1.717	1.716	1.753	1.753

Table 7: 1Hz-EQL Results

NOTE: EQLs computed by DEWI use bin means as the relevant load level!!

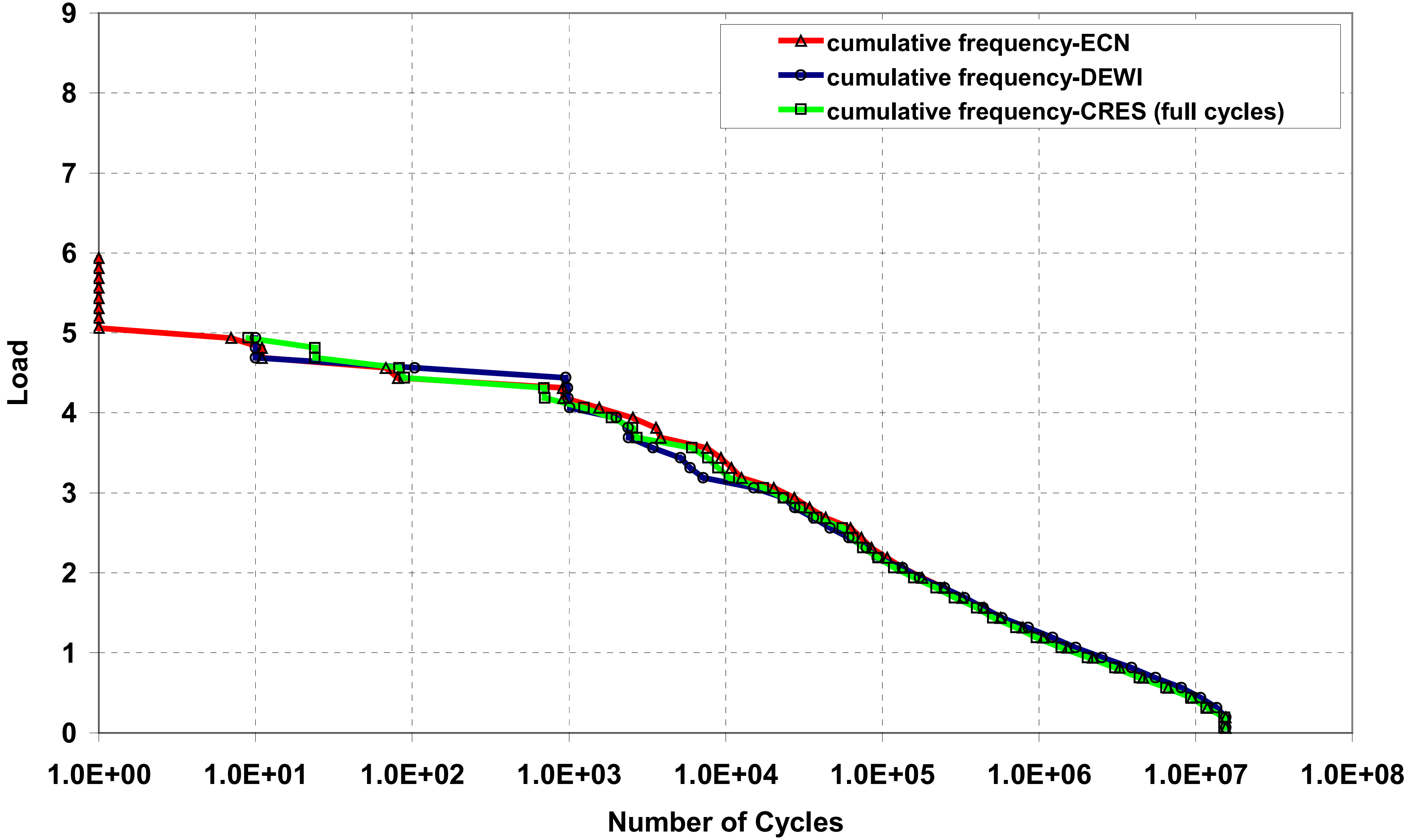

Fig. 1: Normalized Flatwise Range-Pair Spectrum

1.6.1 Results From DEWI

Table 8 gives the normalized flatwise annual range pair spectrum obtained from the sample data set:

Range Pair Spectrum flatwise	DEWI		
Bin	Load in i-th Bin	Cumulative frequency	counts
1	0.0625	15631472	0
2	0.1875	15631472	2021890
3	0.3125	13609582	2875355
4	0.4375	10734227	2639368
5	0.5625	8094859	2560728
6	0.6875	5534131	1630496
7	0.8125	3903635	1373183
8	0.9375	2530452	808622
9	1.0625	1721830	494798
10	1.1875	1227032	374503
11	1.3125	852529	270828
12	1.4375	581701	140772
13	1.5625	440929	104979
14	1.6875	335950	86914
15	1.8125	249036	75565
16	1.9375	173471	38953
17	2.0625	134518	41474
18	2.1875	93044	13496
19	2.3125	79548	18080
20	2.4375	61468	15047
21	2.5625	46421	10038
22	2.6875	36383	8670
23	2.8125	27713	4348
24	2.9375	23365	8269
25	3.0625	15096	7903
26	3.1875	7193	1264
27	3.3125	5929	761
28	3.4375	5168	1719
29	3.5625	3449	1035
30	3.6875	2414	24
31	3.8125	2390	382
32	3.9375	2008	994
33	4.0625	1014	25
34	4.1875	989	6
35	4.3125	983	26
36	4.4375	957	853
37	4.5625	104	94
38	4.6875	10	0
39	4.8125	10	0
40	4.9375	10	10
41	5.0625	0	0
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64	7.9375	0	0

Table 8: DEWI Range-Pair Spectrum

Figure 2 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.

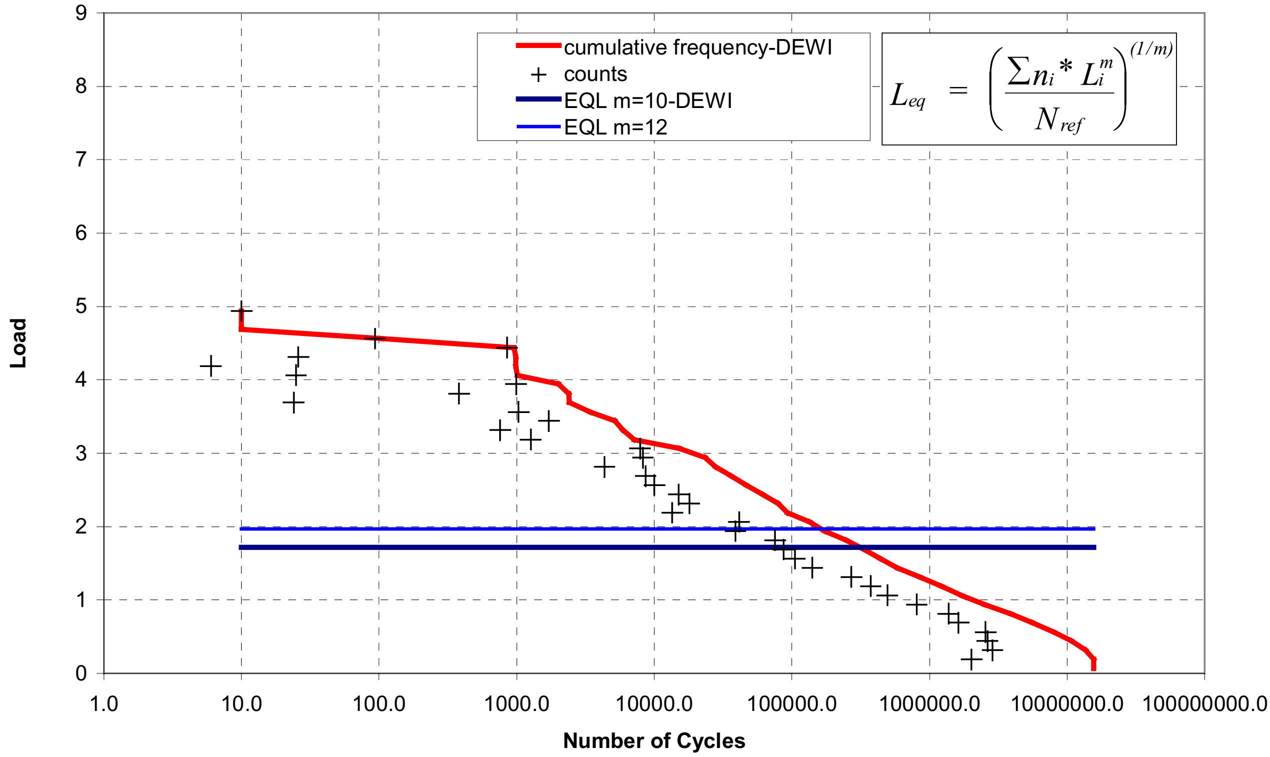

Fig. 2: DEWI's Normalized Flatwise Range-Pair Spectrum and 1-Hz EQL

material exponent m	3	4	6	8	10	12
equiv. No. of cycles	31536000	31536000	31536000	31536000	31536000	31536000
EQL	0.65067	0.80691	1.12697	1.43583	1.71636	1.96451

Table 9: DEWI'S 1Hz-EQL Results

1.6.2 Results From CRES

Following table (Table 10) gives the range spectrum for the flatwise loading obtained from the Rainflow matrix. The matrix data includes the residual counts counted as full cycles and LCF. Rainflow counting matrix has been obtained by an in-house built software using the algorithm described in previous section of this document.

Range Pair Spectrum FLATWISE			
Bin	Load in i-th Bin	Cumulative frequency	full cycle counts
1	0.125	15218378	0
2	0.25	15218378	3511363
3	0.375	11707015	2376778
4	0.5	9330237	2875820
5	0.625	6454417	2059335
6	0.75	4395082	1322636
7	0.875	3072446	1028287
8	1	2044160	652178
9	1.125	1391982	422905
10	1.25	969076.5	253482.5
11	1.375	715594	206752.5
12	1.5	508841.5	107726.5
13	1.625	401115	111543
14	1.75	289572	68407
15	1.875	221165	62476.5
16	2	158688.5	40069
17	2.125	118619.5	24362
18	2.25	94257.5	18920.5
19	2.375	75337	10466.5
20	2.5	64870.5	9191
21	2.625	55679.5	17466.5
22	2.75	38213	8296
23	2.875	29917	6505
24	3	23412	5999.5
25	3.125	17412.5	6846
26	3.25	10566.5	1629.5
27	3.375	8937	1205
28	3.5	7732	1636.5
29	3.625	6095.5	3370.5
30	3.75	2725	171.5
31	3.875	2553.5	676.5
32	4	1877	626.5
33	4.125	1250.5	548
34	4.25	702.5	9
35	4.375	693.5	604.5
36	4.5	89	6.5
37	4.625	82.5	58.5
38	4.75	24	0
39	4.875	24	15
40	5	9	9
41	5.125	0	0
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64	8	0	0

Table 10: CRES Range Spectrum for flatwise load

Figure 3 depicts the range spectrum (cumulative frequency of counted rainflow full cycles) as obtained by using the software built by CRES using the algorithm described in previous section of this document.

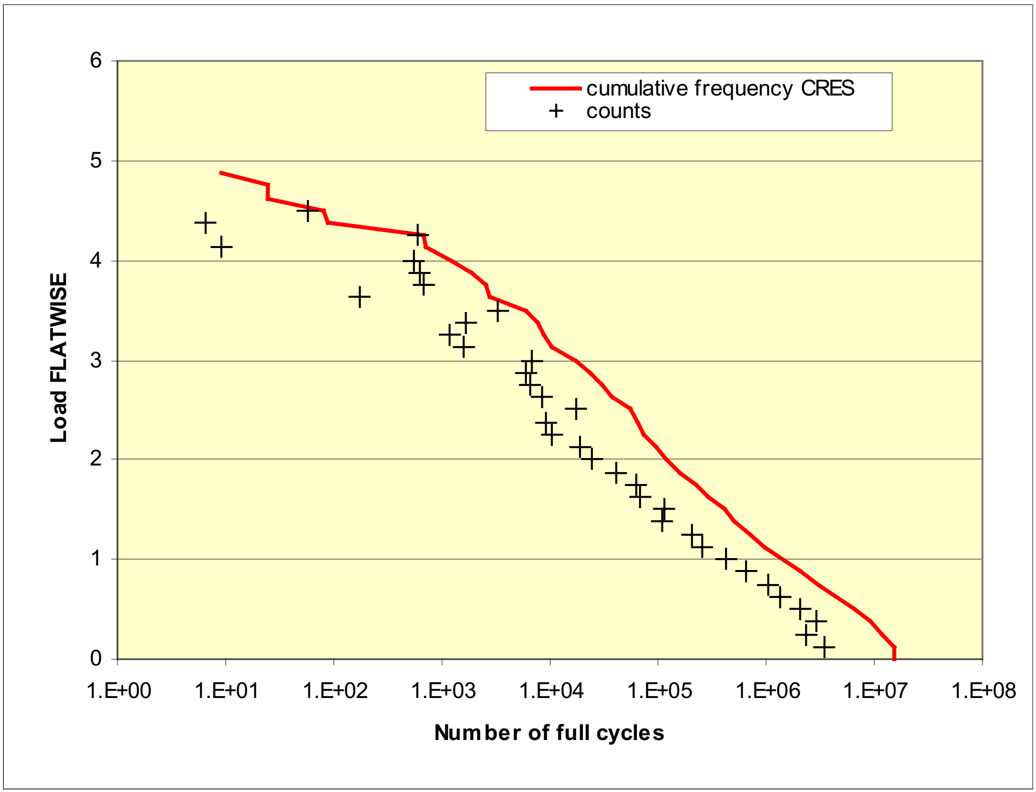

Fig. 3: CRES' Range Spectrum and 1-Hz EQL of Flatwise loads

Material exponent m	**10**
Equiv. No. of cycles	**31536000**
EQL - Flatwise	**1.748**

Table 11: CRES 1Hz- EQL Results

NOTE: Normalization for the cyclic content (rotational speed) has been made for deriving the above results.

EQL uses upper bin boundaries!

1.6.3 Results From ECN

The table below shows the flatwise load spectrum.

bin	load in i-th bin	Counts	Cumulative frequency
1	6	1	1
2	5.875	0	1
3	5.75	0	1
4	5.625	0	1
5	5.5	0	1
6	5.375	0	1
7	5.25	0	1
8	5.125	0	1
9	5	6	7
10	4.875	4	11
11	4.75	0	11
12	4.625	57	68
13	4.5	13	82
14	4.375	833	915
15	4.25	9	923
16	4.125	634	1557
17	4	1004	2561
18	3.875	1046	3607
19	3.75	246	3853
20	3.625	3730	7583
21	3.5	1764	9347
22	3.375	1513	10860
23	3.25	1752	12612
24	3.125	7676	20288
25	3	7144	27432
26	2.875	6957	34389
27	2.75	9000	43389
28	2.625	19338	62727
29	2.5	10835	73562
30	2.375	11982	85544
31	2.25	22010	107554
32	2.125	27203	134757
33	2	45012	179769
34	1.875	68297	248066
35	1.75	76898	324964
36	1.625	121800	446764
37	1.5	120158	566922
38	1.375	222518	789440
39	1.25	276204	1065645
40	1.125	450049	1515693
41	1	686496	2202190
42	0.875	1066423	3268613
43	0.75	1351095	4619708
44	0.625	2051946	6671655
45	0.5	2785645	9457299
46	0.375	2383212	11840511
47	0.25	3698418	15538929
48	0.125	0	15538929
49	1E-33	0	15538929

Table 12 ECN Range Pair Spectrum

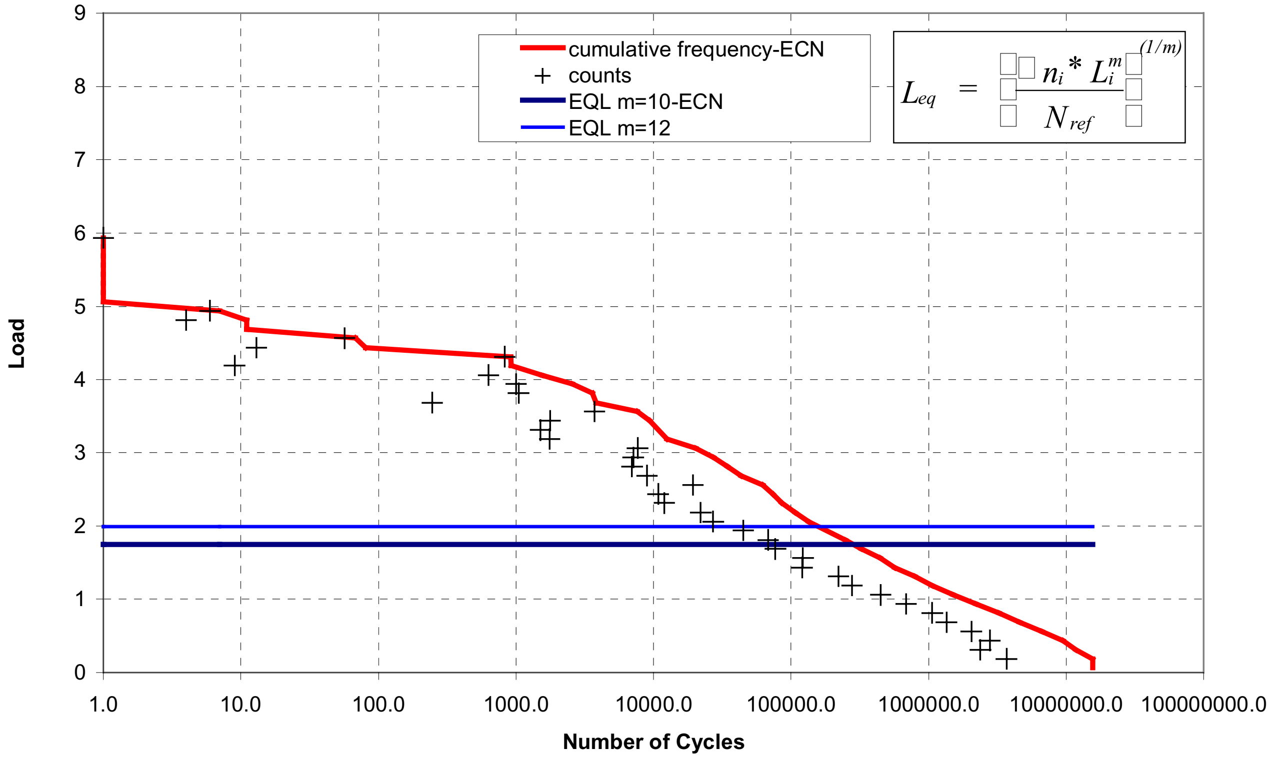

Fig. 4: ECN's Normalized Flatwise Range-Pair Spectrum and 1-Hz EQL

Note: DEWI has recomputed EQL with ECN's range pair spectrum and obtained the following values:

material exponent m	3	4	6	8	10	12
equiv. No. of cycles	31536000	31536000	31536000	31536000	31536000	31536000
EQL	0.6366	0.8094	1.1574	1.477	1.7530	1.9895

Table 9: 1Hz-EQL Results based on ECN's range pair spectrum recomputed by DEWI

1.7 CONCLUSION

- Treatment of residuals is not unique! CRES keeps half cyles, DEWI uses ful cycles (as suggested in the benchmark specs), For full cycle counts the residu is handled by ECN as follows. Depending which has the largest range, the even or odd single ranges are counted as full cycles. As a consequence ECN and CRES only count half as many "residual-full-cycles"
  All partners shall use full cycles for all residual load transitions.

1.8 CONTACT

In case of questions or support is needed turn to

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