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STSM Scientific Report

COST Action TU0904

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Purpose of the visit

STSM was realized in frameworks of benchmark problems preparation for bended steel beams under elevated temperature. During the mission, a series of finite element (FE) models were prepared using commercial version of Vulcan software. Factors influencing results (mid-span deflections) were identified and beams with different loads, boundary conditions and cross-sections were modeled to confirm the analytical computations and results from other FE software.

Description of the work carried out during STSM

During benchmark problems preparation all factors influencing final results must be recognized. To do so, firstly a 1 meter long steel beam with rectangular 50mmx30mm beam was modeled. The material properties were chosen to imitate beam at temperature of 800°C using simplified bilinear material model properties shown in ASFE conference in Prague [1]. This stands for Young's modulus of elasticity equal to 40GPa and σ_y=40MPa. The beam was loaded in constant temperature and the mid-span deflection was taken as a main result.

The influence of number of beam elements and differentiation points through thickness was checked. The beam lenght was divided into 30 or 60 elements (of lengths 33.3 mm and 16.7 mm subsequently). The different number of through-thickness differentiation points was obtained by dividing cross-section into sub-regions (according to paper [2]). Divisions into 2x2, 5x5, 9x9, 15x15, 20x20 and 25x25 sub-regions were used for model with 30 beam elements model while 2x2, 5x5 and 9x9 sub-regions for model with 60 elements were adopted. The simply supported beam was loaded with bending moments by applying force at the ends of stiff cantilevers. The results can be seen on Fig. 1 and Table 2.

Pure bending	
	f [mm]
X-section 2x2, 33,333 lenght	9,325761
X-section 5x5, 33,333 lenght	11,41868
X-section 9x9, 33,333 lenght	10,98268
X-section 15x15, 33,333 lenght	11,31123
X-section 20x20, 33,333 lenght	11,05469
X-section 25x25, 33,333 lenght	11,18237
X-section 2x2, 16,667 lenght	9,32571
X-section 5x5, 16,667 lenght	11,41714
X-section 9x9, 16,667 lenght	10,98112

Table 1. Study of influence of FE mesh density and through-thickness integration points number on results for rectangular cross-section.

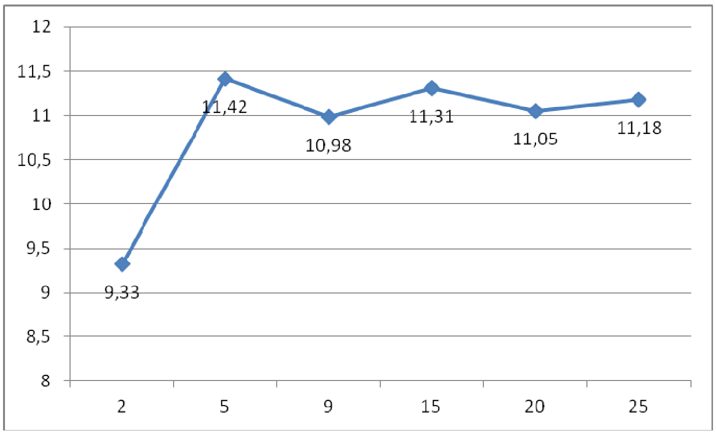


Figure 1. Convergence of results depending on number of sub-regions of rectangular cross-section (number of sub-regions on one side given).

Although the results are waving, a good coincidence with analytical solution can be seen already for 5x5 cross-section division, and while it is increased to 25x25 almost same deflection is obtained. It was also proven that this number of beam elements through member length is appropriate and the result does not change significantly while increasing it.

Next step was to apply different loads and boundary conditions. The cases were divided into two families, differing by load magnitude. First one is with the magnitudes of loads giving bending moment in most stressed cross-section equal to $M=M_E+0.8*(M_{PL} – M_E)$, where M_E is bending moment enabling plasticity in outer fibers of cross-sections, and M_{PL} is the one causing plasticity in whole cross-section. The other family is for loads with coefficient 0.95. The loads and moments magnitudes are shown in Tables 3 and 4. Also analytical solutions are shown there.

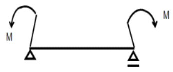
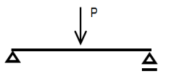
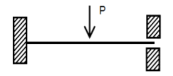
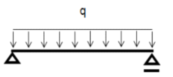
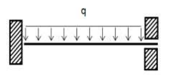
RECTANGULAR CROSS-SECTION (lxhxb) 1000x50x30mm E=40GPa, s0=40MPa N=0 (no longitudinal constraints)										
J=312500mm4, Mel= 500000Nmm Mu=750000Nmm										
			Analytical		Vulcan					
					Mesh 3 (33,3x5,5x3,3)		Mesh 2 (33,3x2,5x1,5)		Mesh 1 (33,3x2,0x1,2)	
#	BC	$M=M_{el}+0.8*(M_u-M_{el})$	f_{el} [mm]	f [mm]	f_{el} [mm]	f [mm]	f_{el} [mm]	f [mm]	f_{el} [mm]	f [mm]
1		M=700000 Nmm	7,0000 $\frac{Ml^2}{8EJ}$	11,1803	7,0841	10,9827	7,0143	11,0547	7,0080	11,1824
2		P=2800 N	4,6667 $\frac{Pl^3}{48EJ}$	5,1596	4,7610	5,2611	4,7143	5,2081	4,7101	5,2000
3		P=5600 N	2,3333 $\frac{Pl^3}{192EJ}$	2,5785	2,4352	2,6955	2,4119	2,6591	2,4098	2,6559
4		q=5,6 N/mm	6,2222 $\frac{ql^4}{72EJ}$	7,4301	5,9416	7,5532	5,8833	7,4779	5,8781	7,4825
5		q=8,4 N/mm	1,7500 $\frac{ql^4}{384EJ}$	1,8216	1,8264	1,9033	1,8090	1,8805	1,8074	1,8783

Table 2. Results for rectangular cross-section, load coefficient 0.80.

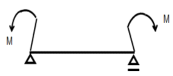
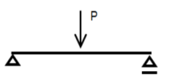
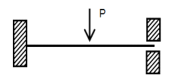
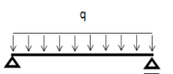
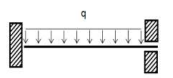
RECTANGULAR CROSS-SECTION (lxhxb) 1000x50x30mm E=40GPa, s0=40MPa N=0 (no longitudinal constraints)										
J=312500mm4, Mel= 500000Nmm Mu=750000Nmm										
			Analytical		Vulcan					
					Mesh 3 (33,3x5,5x3,3)		Mesh 2 (33,3x2,5x1,5)		Mesh 1 (33,3x2,0x1,2)	
#	BC	$M=M_{el}+0.95*(M_u-M_{el})$	f_{el} [mm]	f [mm]	f_{el} [mm]	f [mm]	f_{el} [mm]	f [mm]	f_{el} [mm]	f [mm]
1		M=737500 Nmm	7,3750 $\frac{Ml^2}{8EJ}$	22,3607	7,4633	20,7379	7,3897	20,1379	7,3830	20,3720
2		P=2950 N	4,9167 $\frac{Pl^3}{48EJ}$	6,1275	5,0160	6,3268	4,9668	6,1889	4,9624	6,1732
3		P=5900 N	2,4583 $\frac{Pl^3}{192EJ}$	3,0638	2,5657	3,2396	2,5411	3,1211	2,5389	3,1243
4		q=5,9 N/mm	6,5555 $\frac{ql^4}{72EJ}$	10,7171	6,2598	11,0557	6,1984	10,8031	6,1928	10,7609
5		q=8,85 N/mm	1,8437 $\frac{ql^4}{384EJ}$	--	1,9243	2,0593	1,9059	2,0413	1,9042	2,0376

Table 3. Results for rectangular cross-section, load coefficient 0.95.

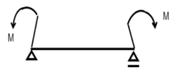
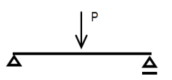
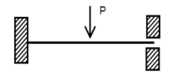
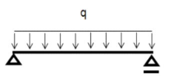
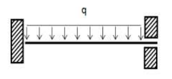
UB496x178x67 l=8000 mm E=40GPa, s0=40MPa N=0 (no longitudinal constraints)										
J=2.4015×10^8 mm^4, Mel= 4.6927×10^7 Nmm , Mf=4.8915×10^7 Nmm, Mu=5.3169×10^7 Nmm										
			Analytical		Vulcan					
					Mesh 3 (133x34x15)		Mesh 2 (133,3x20x9)		Mesh 1 (133,3x17x7,5)	
#	BC	$M=M_{el}+0.8*(M_u-M_{el})$	f_{el} [mm]	f [mm]	f_{el} [mm]	f [mm]	f_{el} [mm]	f [mm]	f_{el} [mm]	f [mm]
1		M=5.19206E+7 Nmm	43,2405 $\frac{Ml^2}{8EJ}$	77,5557	43,3154	77,6325	43,2670	77,1231	43,2595	76,8991
2		P=25960.3 N	28,8270 $\frac{Pl^3}{48EJ}$	28,9369	29,3631	30,8757	29,3294	30,7664	29,3244	30,7611
3		P=51920,6 N	14,4134 $\frac{Pl^3}{192EJ}$	--	15,3998	16,1075	15,3829	16,1002	15,3804	16,0814
4		q=6,49008 N/mm	38,4357 $\frac{ql^4}{72EJ}$	42,4408	36,5825	45,2064	36,5404	44,9249	36,5342	44,8710
5		q=9,7351125 N/mm	10,8100 $\frac{ql^4}{384EJ}$	--	11,5499	11,7563	11,5373	11,7369	11,5354	11,7310

Table 4. Results for I-beam, load coefficient 0.80.

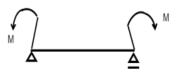
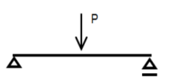
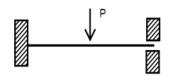
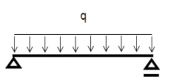
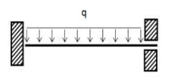
UB496x178x67 l=8000 mm E=40GPa, s0=40MPa N=0 (no longitudinal constraints)										
J=2.4015×10^8 mm^4, Mel= 4.6927×10^7 Nmm , Mf=4.8915×10^7 Nmm, Mu=5.3169×10^7 Nmm										
			Analytical		Vulcan					
					Mesh 3 (133x34x15)		Mesh 2 (133,3x20x9)		Mesh 1 (133,3x17x7,5)	
#	BC	$M=M_{el}+0.95*(M_u-M_{el})$	f_{el} [mm]	f [mm]	f_{el} [mm]	f [mm]	f_{el} [mm]	f [mm]	f_{el} [mm]	f [mm]
1		M=5.28569E+7 Nmm	44.0203 $\frac{Ml^2}{8EJ}$	155,1110	44,0960	133,3375	43,6569	135,9685	44,0392	--
2		P=26428.5 N	29,3469 $\frac{Pl^3}{48EJ}$	31,5555	29,8926	33,6005	29,8583	33,2939	29,8532	33,2742
3		P=52856,9 N	14,6733 $\frac{Pl^3}{192EJ}$	--	15,6775	17,2481	15,5800	17,2415	15,6578	17,2419
4		q=6,6071 N/mm	39,1292 $\frac{ql^4}{72EJ}$	57,0720	37,2420	60,5958	37,1991	--	37,1928	--
5		q=9,91066875 N/mm	11,0050 $\frac{ql^4}{384EJ}$	--	11,7582	12,1158	11,7453	12,0991	11,7434	12,0944

Table 5. Results for I-beam, load coefficient 0.95.

Each case was modeled using two material models: the bilinear one, with E=40Gpa and σ_Y=40MPa, and the fully elastic one, with E=40Gpa. It was done to check correctness of the models and all the solutions. Deflections for fully elastic material model are marked as f_{el}.

Similar investigations were done for 8 meters long UB 406x178x67 I-beam. Results can be seen on tables 4 and 5. Some of analytical results were not obtained yet and are to be calculated. Also some of FE results were not obtained. The FIRE software is usually used for different kinds of analyses, thus for some cases results could not be obtained due to lack of convergence of subsequent iterations during calculation procedure. These results will be checked by means of other FE programs (LS-Dyna and Abaqus).

Description of the main results obtained

All the results for load coefficients 0.8 shows good similarity to analytical ones and to those obtained in other finite element programs. Unfortunately, due to rapid change of deflection while plasticity phenomena occurs in I-beam, some of the models could be correctly computed for load coefficient 0.95. Also some of results shows different deflections of the beams for load coefficient of 0.95, probably also due to rapid change of displacements. These results will be obtained by other FE software to prove correctness of analytical solutions already done and these to be obtained.

Future collaboration with host institution (if applicable)

The collaboration with the University of Sheffield gave possibility of obtaining by means of Vulcan software results, which confirm correctness of models done in Abaqus and LS-DYNA and analytical solutions. The experience of professor Burgess would be very helpful in later stages of benchmarks preparation.

Foreseen publications/articles resulting or to result from the STSM

The benchmark problems which were investigated during STSM are planned to be published later this year, in frameworks of COST action.

References

[1] Sawicki B., Pełczyński J., Kwaśniewski L. „BENCHMARK EXAMPLE PROBLEMS FOR BEAMS At Elevated Temperatures”, APPLICATIONS OF STRUCTURAL FIRE ENGINEERING, pp.29-35, CTU Publishing House, Prague 2013

[2] Jun Cai, Burgess, I.W. and Plank, R.J., 'Modelling of Asymmetric Cross-Section Members for Fire Conditions', J. Construct. Steel Research. 58 (3),(2000) pp389-412.

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