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Accurate Small Sized Load Bearing Components Displacement Analysis

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Abstract

Load bearing components with cross sections in scale of millimeters attracted popularity with the advance in material engineering. As standard size scale of load bearing structures are around 100 times bigger than millimeter sized components, classical stability analyzes may be insufficient to simulate all stress and strains in load bearing structures which may lead to fail in whole structure. In this paper, the displacement analysis of small cross-sectional load bearing metals is presented using finite element analyzes and higher order elasticity theory. To take the size effect into consideration surface elasticity theory is selected. It is obtained higher order analyzes results differs from F.E.A. results. This result reveals that classical methods are insufficient to give accurate success in millimeters scale.

Keywords: ANSYS, Small cross section, Stability, Structural Steel, Surface Elasticity.

1. Introduction

Progress in materials engineering in recent years has been enormous, as has progress in small-scale engineering. Metal-based components such as aluminum, which are traditionally used as weak but inexpensive, have recently been strengthened and used as both durable and inexpensive materials. Durable material symbolizes that the load to which the material will be exposed at the application area is multiplied by a certain safety factor, and that it can safely carry the service load to be obtained, complies with the definition of durable material for the end user and engineers. Other prominent features of metal-based component can be stated as light-weight and ease to working on such as cutting and welding.

Traditional houses need to be constructed with components in meter scale while this has changed in some circumstance. Due to the rise in interest to living in tiny houses the size of structural elements used in constructions got smaller sizes. It is seen that the effects of the structural load and environmental loads that the carrier components will carry in the construction will be much smaller compared with traditional structures [1]. The decrease in carrying load will lead to decrease in structural components. Furthermore, the progress in composite materials allows to use more durable composite structural components with lower production cost [2, 3]. Furthermore, the advance in composite material allow to use components with smaller cross section [4]. Composite materials has the advantage of customize the end product in the way needed [5].

Analyzes on composite structures are not as formidable as analyzes on nanostructures. Setting up a new laboratory to perform nano sized analyzes can reach astronomical costs while the cost is lower in millimeter scaled engineering. Due to the ease of perform multiple analyzes at same time and no need to laboratory, researchers prefer to perform analyzes using classical mechanic [6-9] which leads to give non-accurate results, taking the size effect into consideration using higher order continuum theories such as strain gradient [10-13], modified strain gradient [12], couple stress [11, 14, 15], modified couple stress [16, 17], nonlocal elasticity [18-21], surface elasticity [22-26] etc. Also, finite element [27, 28] and DSC method [29-34] methods were also used to perform analyzes. Furthermore, modal and bending analyzes of nano sized structures has been investigated using classical and size effective theories [35-43].Theoretical works are promising in case of the ability to perform hundreds of analyzes in very short time without the need of a laboratory and specimen [44-53].

Owing to the development in material technology, carrier components with much smaller cross-sectional areas are now being used in the skeletons of structures. Aluminum is frequently used in non-bearing components in structures due to its low price and ease of processing [54]. Due to the developments in composite materials, it has now been possible to find composite materials that are much more durable than aluminum [55, 56]. Although the price of these composite materials is not very low, composite materials are gradually replacing structural steel for ease of use in small areas and to avoid production-transport costs [57, 58].

In this paper the displacement analyzes of traditional and small sized components are performed using finite element analysis (F.E.A.) and surface energy theory.

2. Traditional and Small Sized Load Bearing Components

Traditional steel has been used in meter scale in constructions since more than a century with cross sections in centimeter scale. Accurate performance analyzes has been made for traditional scale not only for structural steel but for other metals and metal based composites. Both in meter and millimeter scaled structural steel analyzes will be performed using ANSYS and surface energy theory.

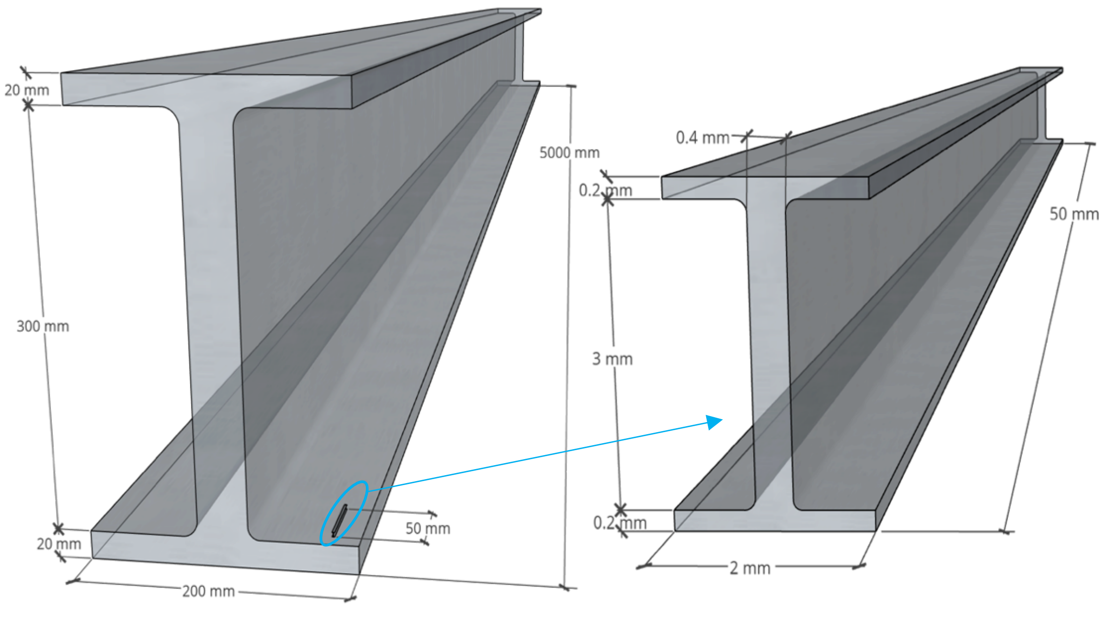

Fig. 1. Traditional vs. small sized load bearing structural steel

Examined structural load bearing components are selected with standard I cross section. The difference between the size scale of small sized and traditional components is demonstrated in left side of Fig. 1 by locating the small sized component at the right-bottom side of traditional sized component (in blue circle). Detailed geometric values of two components are also given in Fig. 1.

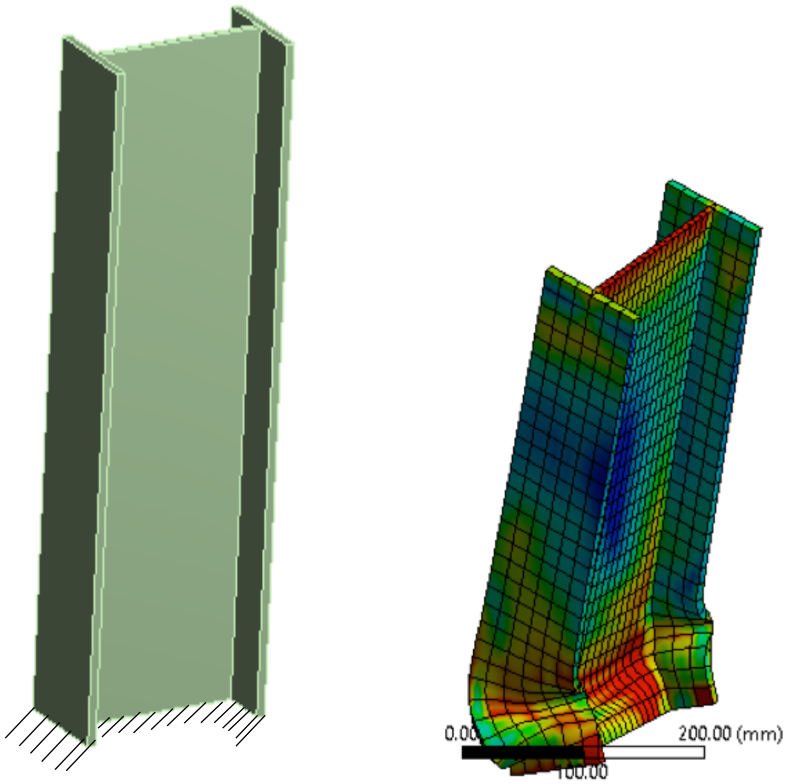

Fig. 2. Unloaded vs loaded structure component

The unloaded and loaded components are demonstrated in Fig. 2. As it can be seen from the figure the component is fixed from the bottom side to the ground while the load is applied to the top side of component. The stress distribution in component body is demonstrated in blue-red graded gradient. Also, the meshing is shown at the right side of Figure 2.

3. Finite Element Analysis and Surface Energy Theory

Traditional steel has been used in meter scale in constructions since more than a century with cross sections in centimeter scale. Accurate performance analyzes has been made for traditional scale not only for structural steel but for other metals and metal based composites. Both in meter and millimeter scaled structural steel analyzes will be performed using F.E.A. software ANSYS and surface energy theory.

When the displacement is equal to zero, the residual surface tension has no effect. But in case of any displacement, the residual surface tension creates a transversely distributed load "q(x)" in the longitudinal direction. This distributed load (Laplace-Young) can be expressed as:

$$q(x) = H\frac{d^2w}{dx^2} - k_w w + k_p\frac{d^2w}{dx^2} \quad (1)$$

The parameter "H" given in Eq. (1) is a constant depending on the residual surface tension and can be calculated as [59]:

$$H = 2\tau^0 h \quad (2)$$

Where "τ^0" is residual surface tension. Substituting Eq. (2) in Eq. (1):

$$(-\overline{EI} + P\mu - H\mu - k_p\mu)\frac{\partial^4 w}{\partial x^4} + (H + k_w\mu - P + k_p)\frac{\partial^2 w}{\partial x^2} - k_w w = 0 \quad (3)$$

Here "μ" is the non-local parameter and is equal to $(e_0 a)^2$, "k_w" and "k_p" are the foundation parameters "Winkler" and "Pasternak" respectively wich will be neglected in current calculations.

4. Result and Discussions

Results are obtained using 0.2 second time step. Structural steel is selected as both traditional and small scaled components with geometric values given in Figure 1. In Table 1 F.E.A. results are given for structural steel with traditional and small size. Specimens are selected in geometric values given in Figure 1 without foundation effect. Displacements of component top part, force reaction at the fixed end and maximum stress in component body are calculated for each time step until 5.4 seconds. Results are given in Table 1 comparing traditional and small sized components.

Table 1. F.E.A. results

	Traditional Component			***Small Sized Component***		
Time	Displacement (mm)	Force reaction (N)	MAX stress (MPa)	Displacement (mm)	Force reaction (N)	MAX stress (MPa)
0.2	0.1838	8222.50	36.2470	0.01080882	483.676471	2.13217647
0.4	0.3675	16445.00	72.5400	0.02161765	967.352941	4.26705882
0.7	0.5513	24667.00	108.8800	0.03242647	1451	6.40470588
1	0.7350	32890.00	145.2600	0.04323529	1934.70588	8.54470588
1.2	0.9188	41112.00	181.6800	0.05404412	2418.35294	10.6870588
1.4	1.1025	49335.00	218.1500	0.06485294	2902.05882	12.8323529
1.6	1.2862	57557.00	254.6700	0.07565882	3385.70588	14.9805882
1.8	1.4700	65753.00	237.1200	0.08647059	3867.82353	13.9482353
2	1.6537	73241.00	236.8200	0.09727647	4308.29412	13.9305882
2.2	1.8375	77481.00	237.2600	0.10808824	4557.70588	13.9564706
2.4	1.4700	61032.00	195.4500	0.08647059	3590.11765	11.4970588
2.6	1.1025	44587.00	153.8400	0.06485294	2622.76471	9.04941176
2.8	0.7350	28142.00	112.8000	0.04323529	1655.41176	6.63529412
3	0.3675	11697.00	73.3620	0.02161765	688.058824	4.31541176

3.2	0.0000	-4747.50	73.1190	-9.143E-17	-279.26471	4.30111765
3.4	-0.3675	-21192.00	132.9100	-0.0216176	-1246.5882	7.81823529
3.6	-0.7350	-37637.00	193.2400	-0.0432353	-2213.9412	11.3670588
3.8	-1.1025	-54022.00	235.0000	-0.0648529	-3177.7647	13.8235294
4	-1.4700	-68985.00	235.0000	-0.0864706	-4057.9412	13.8235294
4.2	-1.8375	-77491.00	236.7400	-0.1080882	-4558.2941	13.9258824
4.4	-1.4700	-61044.00	191.5000	-0.0864706	-3590.8235	11.2647059
4.6	-1.1025	-44599.00	150.4100	-0.0648529	-2623.4706	8.84764706
4.8	-0.7350	-28154.00	109.9700	-0.0432353	-1656.1176	6.46882353
5	-0.3675	-11710.00	71.8930	-0.0216176	-688.82353	4.229
5.2	0.0000	4735.20	73.7120	-2.874E-16	278.541176	4.336
5.4	0.3675	21180.00	133.3000	0.02161765	1245.88235	7.84117647

After the load is applied from the upper end to the component, which is stationary at the initial moment, displacement, force reaction and maximum stresses are calculated for each 0.2 second time interval, respectively, and the results are shown in Table 1. Similar to first loading cycle the load was applied in a cyclic manner, pushing and pulling. Different responses to load cycle were observed for conventional and small scaled components during the loading. Obtained higher order results indicate that the scale effect is affecting the behavior and internal forces in component body.

Table 2. Higher order results

	Traditional Component			***Small Sized Component***		
Time	Displacement (mm)	Force reaction (N)	MAX stress (MPa)	Displacement (mm)	Force reaction (N)	MAX stress (MPa)
0.2	0.1838	8222.50	36.2470	0.01307225	490.991759	2.16651498
0.4	0.3675	16445.00	72.5400	0.02404451	981.981418	4.33367675
0.7	0.5513	24667.00	108.8800	0.03501676	1472.94122	6.50364504
1	0.7350	32890.00	145.2600	0.04598901	1963.96074	8.67600184
1.2	0.9188	41112.00	181.6800	0.05696126	2454.92054	10.8507472
1.4	1.1025	49335.00	218.1500	0.06793352	2945.94005	13.0284781
1.6	1.2862	57557.00	254.6700	0.07890278	3436.89986	15.2091947
1.8	1.4700	65753.00	237.1200	0.08987802	3926.30712	14.1612326
2	1.6537	73241.00	236.8200	0.10084729	4373.43762	14.1433187
2.2	1.8375	77481.00	237.2600	0.11182253	4626.6205	14.1695924
2.4	1.4700	61032.00	195.4500	0.08987802	3644.40233	11.6729944
2.6	1.1025	44587.00	153.8400	0.06793352	2662.42301	9.18833887
2.8	0.7350	28142.00	112.8000	0.04598901	1680.44369	6.73771976
3	0.3675	11697.00	73.3620	0.02404451	698.464373	4.38276079
3.2	0.0000	-4747.50	73.1190	0.0021	-283.48509	4.36825055
3.4	-0.3675	-21192.00	132.9100	-0.0198445	-1265.4345	7.93854701
3.6	-0.7350	-37637.00	193.2400	-0.041789	-2247.4139	11.5410288
3.8	-1.1025	-54022.00	235.0000	-0.0637335	-3225.8104	14.0346412
4	-1.4700	-68985.00	235.0000	-0.085678	-4119.2951	14.0346412
4.2	-1.8375	-77491.00	236.7400	-0.1076225	-4627.2134	14.1385417
4.4	-1.4700	-61044.00	191.5000	-0.085678	-3645.1147	11.4371282

4.6	-1.1025	-44599.00	150.4100	-0.0637335	-2663.1354	8.98352348
4.8	-0.7350	-28154.00	109.9700	-0.041789	-1681.156	6.56873214
5	-0.3675	-11710.00	71.8930	-0.0198445	-699.23644	4.29504248
5.2	0.0000	4735.20	73.7120	0.0021	282.754819	4.40366032
5.4	0.3675	21180.00	133.3000	0.02404451	1264.72219	7.96183506

4. Conclusions

Cross-sections of structural components get smaller everyday with the advance in material and composite engineering. As the conventional and small scaled components have 100 times difference in size, the effect of small cross-section should be taken into consideration using higher order theories. In this paper the displacement analysis of conventional and small scaled structural components is investigated using finite element method and surface energy theory. Maximum displacements, force reactions at fixed end, and maximum stress in the component body for two specimens is compared. It is clearly seen that the effect of small scale should not be neglected as results differs in this scale.

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