CFSM and GBT: Elastic Buckling Behaviour and Capacity of CFS Purlins and Girts Under Uplift Loading Condition

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Abstract:- **Objective of this work is to study the elastic buckling behavior and load carrying capacity of purlins and girts. 30 specimens including both "C" and "Z" sections are chosen from literature survey especially from research work of TianGao. For these sections buckling behavior is studied using CUFSM and GBTUL software and load factor is compared with that obtained from experimental study of TianGao. Lateral restraint of sheeting is introduced as springs in analytical study and behavior observed. For purlins author did not included orientation of purlin as criteria, in this study orientation of purlin also included as prime factor. Based on CUFSM and GBTUL analytical result design capacity of purlins and girts are obtained and compared with experimental studies from literature.**

Keywords: CUFSM, GBTUL, failure modes, rotational restraint, purlin orientation

1. INTRODUCTION

Cold formed steel sections are thin sections made out of thin sheets of steel by rolling or press braking method in cold state. These sections are having uniform thickness. These sections are also called Light Gauge Steel Sections or Cold Rolled Steel Sections. Cold formed steel is used as secondary structural members like purlins and girts.Cold formed steel sections are thin in cross section and fails by buckling prior to yielding. Different modes of failure are observed in cold formed steel like local buckling, distortional buckling and lateral distortional buckling. [1]

1.1. FOCUS ON STUDY

The main aim is to study the behaviour of purlins and girts under uplift condition in metal roof construction with considering rotational restraint due to roof covering sheet profile. An extension of research work by TianGao. [4][5]

1.1.1. Rotational Restraint

Roof covering sheets creates restraint to compression flange of purlin and cladding provides restraint to flanges of girts. Rotational restraint creates behaviour differ both in purlins and girts as mode of failure changes. In AISI method rotational restraint is not taken in to consideration for design purpose. TianGao initiated research in considering rotational restraint in metal roof construction. Shear flow generated because of major axis bending causes the section to rotate. TianGao conducted experiments [4] to predict R factor to determine yield moment in AISI method and found experimental results comes nearer to predicted result. Predicted stiffness value is based on considering rotation of specimen as deflection of cantilever beam. Flange connecting with roof covering sheet becomes fixed end and another flange is free end. TianGao also conducted flexural experiment to estimate the strength of purlins and girts and also to examine failure modes like failure of screw and failure of cladding sheet by creating suction pressure as uniform load.

2. METHODOLOGY

From the experimental study conducted by TianGao [4][5] 30 specimens were chosen to conduct parametric study. As initial part of study 10specimens were taken and studied their parameters using CUFSM and GBTUL Software. CUFSM software is based on Finite Strip Method (FSM). The best known of numerical methods developed for analyzing cold formed steel sections based on the separation of variables is perhaps the Finite Strip Method. Finite Strip Method is quite economical with respect to the computational efficiency. The Finite Strip Method can be considered as a specialization of FEM. Unfortunate

Table I Section Properties Zed profile

S.NO	Test Name	CROSS SECTION - Zed Profile											fy (N/sq.mm)
		COMPRESSION FLANGE				TENSION FLANGE							
		B (mm)	D (mm)	α (deg.)	θ (deg.)	B (mm)	D (mm)	α (deg.)	θ (deg.)	H (mm)	r (mm)	t (mm)	
1	Z200D-2	68.4	26.4	92	47	72.5	27.5	92	53	202	6.6	2.59	420
2	Z250B-1	71.7	21.1	91	55	72.9	22.1	90	47	253	5.9	1.51	401
3	Z200D-R100-1	67.9	25.2	90	48	67.9	27.6	90	53	205	5.7	2.54	428
4	Z200D-TH25-2	66.1	26.3	90	47	69.4	26.3	89	53	205	6.3	2.54	418
5	Z250B-TH100-1	68	18	90	53	72.9	20	88	45	254	5.1	1.52	388

Table II Section Properties Zed profile

S.NO	Test Name	CROSS SECTION - Channel Profile											fy (N/sq.mm)
		COMPRESSION FLANGE				TENSION FLANGE							
		B (mm)	D (mm)	α (deg.)	θ (deg.)	B (mm)	D (mm)	α (deg.)	θ (deg.)	H (mm)	r (mm)	t (mm)	
1	C200D-1	65.2	21.3	92	90	65	21.7	92	90	203	5.1	2.57	522
2	C200D-TH25-1	63.8	21	93	90	64.5	21	93	90	203	4.8	2.57	525
3	C200D-TH50-1	61.5	21.2	91	90	62.8	20.2	91	90	203	4	2.58	514
4	C250D-TH25-1	63.1	21.2	89	90	63.2	20.9	89	90	254	4.3	1.49	411
5	C250D-TH100-1	64.1	19.7	90	89	65.2	18.9	90	89	254	4.4	1.5	417

the applicability of the FSM to various geometries or boundary loading conditions introduced is weak. In the buckling analysis of thin walled beams using the FSM difficulties are experienced for example when dealing with non-periodic buckling modes or shapes with high gradients. The Finite Strip Method is so named, because only a single element (strip) is used to model the longitudinal direction. [3] GBTUL is based on Generalized Beam Theory. Generalized Beam Theory is an extension to conventional engineering beam theory that allows cross-section distortion to be considered. Stability analysis of thin-walled members may also be performed using GBT. GBT was originally developed by Schardt in Germany, then extended by Davies. Currently, no code exists in the public domain for the application of GBT. However, Camotim and Silvestre have recently supplied code focusing on distortional buckling of C and Z sections common in cold-formed steel. A particular advantage of this implementation is the ability to consider the impact of different end conditions.[2]Both considering rotational restraint and neglecting rotational restraint were taken different cases of main study. As TianGao not extended research up to analytical study but limited to experimental study, here analytical studies were focused. TianGao not considered the roof angle while studying purlin parameters which also considered here.

Table III Stiffness value

Table IV Section Properties and Yield Moment

	Test Name	**Area A mm^2**	**Section Modulus Z mm^3**
1	Z200D-2	1112.70	68497.92
2	Z250B-1	721.54	86445.04
3	Z200D-R100-1	1066.77	69431.99
4	Z200D-TH25-2	1072.57	69571.28
5	Z250B-TH100-1	693.54	84093.49
6	C200D-1	1034.83	68768.31
7	C200D-TH25-1	1023.09	68694.57
8	C200D-TH50-1	1002.38	68155.43
9	C250D-TH25-1	664.45	84678.51
10	C250D-TH100-1	669.15	84855.49

S.No	**Test Name**	**Stiffness value K Nmm/rad/mm**
1	Z200D-2	1339
2	Z250B-1	1342
3	Z200D-R100-1	994
4	Z200D-TH25-2	1339
5	Z250B-TH100-1	1342
6	C200D-1	941
7	C200D-TH25-1	941
8	C200D-TH50-1	941
9	C250D-TH25-1	1151
10	C250D-TH100-1	1151

Table V CUFSM Girts and Purlins – Zed and Channel profile with roof angle as zero without rotational restraint

S. No	Test Name	Crippling Moment McrKNm		
		Local	Distortional	Global
1	Z200D-2	35.09	16.68	1.72
2	Z250B-1	15.25	8.31	0.34
3	Z200D-R100-1	38.33	17.83	0.29
4	Z200D-TH25-2	38.67	16.86	0.29
5	Z250B-TH100-1	16.31	7.83	0.32
6	C200D-1	48.45	25.84	0.35
7	C200D-TH25-1	50.84	27.04	0.36
8	C200D-TH50-1	55.35	29.42	0.35
9	C250D-TH25-1	21.22	17.05	0.34
10	C250D-TH100-1	21.93	16.27	0.35

Table VI CUFSM Girts and Purlins – Zed and Channel profile with roof angle as zero with rotational restraint

S. No	Test Name	Crippling Moment McrKNm		
		Local	Distortional	Global
1	Z200D-2	35.09	16.68	12.94
2	Z250B-1	15.25	8.66	10.05
3	Z200D-R100-1	38.33	18.12	13.67
4	Z200D-TH25-2	38.67	17.15	13.66
5	Z250B-TH100-1	16.31	8.15	7.83
6	C200D-1	48.45	26.19	19.73
7	C200D-TH25-1	50.84	27.40	19.83
8	C200D-TH50-1	55.34	29.42	19.61
9	C250D-TH25-1	21.22	17.40	10.78
10	C250D-TH100-1	21.93	16.27	10.61

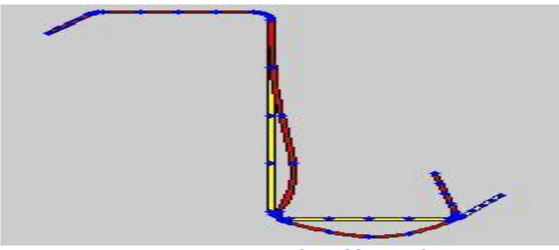

Figure 1: Z200D2 Local Buckling without restraint

S. No	Test Name	Crippling Moment McrKNm		
		Local	Distortional	Global
1	Z200D-2	45.16	28.19	0.28
2	Z250B-1	14.90	14.21	0.34
3	Z200D-R100-1	46.66	29.42	0.29
4	Z200D-TH25-2	47.69	27.91	0.29
5	Z250B-TH100-1	15.33	12.72	0.32
6	C200D-1	67.83	27.99	0.35
7	C200D-TH25-1	70.32	28.48	0.36
8	C200D-TH50-1	74.26	30.12	0.35
9	C250D-TH25-1	22.27	16.74	0.34
10	C250D-TH100-1	22.28	15.92	0.35

Table VII CUFSM Purlins – Zed and Channel profile with roof angle as 10 degrees without rotational restraint

Table VIII CUFSM Purlins – Zed and Channel profile with roof angle as 10 degrees with rotational restraint

S. No	Test Name	Crippling Moment McrKNm		
		Local	Distortional	Global
1	Z200D-2	45.16	28.77	12.08
2	Z250B-1	14.90	14.55	7.97
3	Z200D-R100-1	46.66	30.01	11.88
4	Z200D-TH25-2	47.69	28.49	12.50
5	Z250B-TH100-1	15.33	13.04	6.52
6	C200D-1	67.83	27.99	16.51
7	C200D-TH25-1	70.32	28.48	16.22
8	C200D-TH50-1	74.26	30.47	16.11
9	C250D-TH25-1	22.27	17.05	8.35
10	C250D-TH100-1	22.28	16.27	8.13

Figure 2: Z200D2 Distortional Buckling without restraint

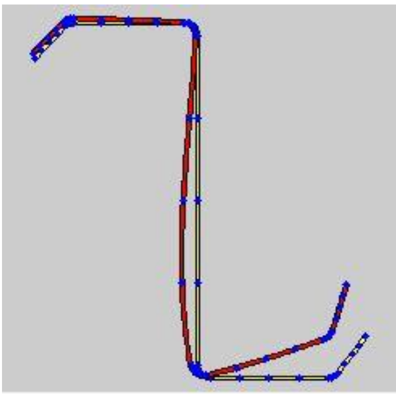

Table IX CUFSM Purlins – Zed and Channel profile with roof angle as 15 degrees without rotational restraint

S. No	Test Name	Crippling MomentMcrKNm		
		Local	Distortional	Global
1	Z200D-2	45.45	28.48	0.86
2	Z250B-1	13.86	14.21	0.35
3	Z200D-R100-1	45.47	30.31	0.29
4	Z200D-TH25-2	45.36	28.78	0.29
5	Z250B-TH100-1	15.00	13.04	0.32
6	C200D-1	66.03	29.07	0.35
7	C200D-TH25-1	67.79	29.20	0.36
8	C200D-TH50-1	70.06	29.07	0.35
9	C250D-TH25-1	19.14	16.70	0.34
10	C250D-TH100-1	22.64	15.92	0.35

Table X CUFSM Purlins – Zed and Channel profile with roof angle as 15 degrees with rotational restraint

S. No	Test Name	Crippling MomentMcrKNm		
		Local	Distortional	Global
1	Z200D-2	45.45	29.05	12.65
2	Z250B-1	13.86	14.21	7.62
3	Z200D-R100-1	45.47	30.91	11.88
4	Z200D-TH25-2	45.36	29.37	11.62
5	Z250B-TH100-1	15.00	13.37	6.85
6	C200D-1	66.03	29.42	16.15
7	C200D-TH25-1	67.79	29.56	16.22
8	C200D-TH50-1	70.06	29.42	15.76
9	C250D-TH25-1	19.14	16.70	8.00
10	C250D-TH100-1	22.64	16.27	8.49

Figure 3: Z200D2 Global Buckling without restraint

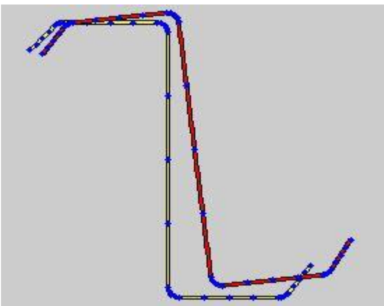

Table XI GBTUL Girts and Purlins – Zed and Channel profile with roof angle as zero without rotational restraint

S. No	Test Name	Crippling Moment McrKNm		
		Local	Distortional	Global
1	Z200D-2	16.58	10.44	1.8
2	Z250B-1	54.37	8.94	3.53
3	Z200D-R100-1	15.94	10.43	0.50
4	Z200D-TH25-2	17.87	8.94	3.53
5	Z250B-TH100-1	73.90	8.94	3.53
6	C200D-1	8.47	5.16	0.69
7	C200D-TH25-1	17.87	8.94	3.53
8	C200D-TH50-1	26.38	9.32	0.35
9	C250D-TH25-1	5.13	3.29	0.11
10	C250D-TH100-1	5.60	2.79	0.12

Table XII GBTUL Girts and Purlins – Zed and Channel profile with roof angle as 10 degrees without rotational restraint

S. No	Test Name	Crippling Moment McrKNm		
		Local	Distortional	Global
1	Z200D-2	15.80	10.04	0.54
2	Z250B-1	2.82	2.82	0.40
3	Z200D-R100-1	16.14	10.51	0.50
4	Z200D-TH25-2	16.79	9.50	0.49
5	Z250B-TH100-1	2.98	2.33	0.23
6	C200D-1	25.68	8.42	0.37
7	C200D-TH25-1	26.21	8.41	0.36
8	C200D-TH50-1	26.55	8.82	0.35
9	C250D-TH25-1	4.90	2.98	0.11
10	C250D-TH100-1	5.33	2.79	0.12

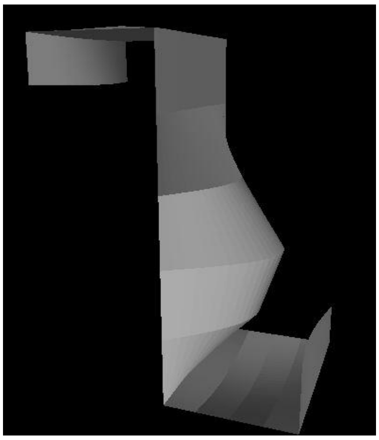

Figure 4: Z200D2 Local buckling with restraint

Table XIII GBTUL Girts and Purlins – Zed and Channel profile with roof angle as 15 degrees without rotational restraint

S. No	Test Name	Crippling Moment McrKNm		
		Local	Distortional	Global
1	Z200D-2	17.17	10.38	0.54
2	Z250B-1	2.83	2.75	0.24
3	Z200D-R100-1	15.74	10.70	0.50
4	Z200D-TH25-2	17.02	9.73	0.49
5	Z250B-TH100-1	2.98	2.33	0.23
6	C200D-1	24.69	8.49	0.37
7	C200D-TH25-1	25.84	8.77	0.36
8	C200D-TH50-1	27.53	8.33	0.35
9	C250D-TH25-1	4.99	2.85	0.11
10	C250D-TH100-1	5.31	2.77	0.12

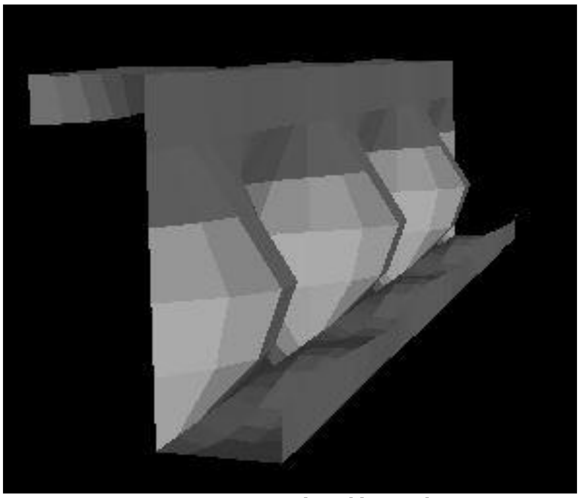

Figure 5: Z200D2Distortional Buckling with restraint

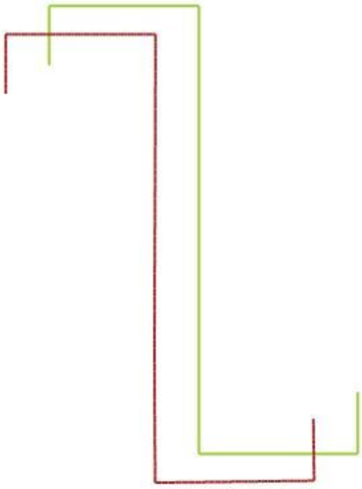

Figure 6: Z200D2 Global buckling with restraint

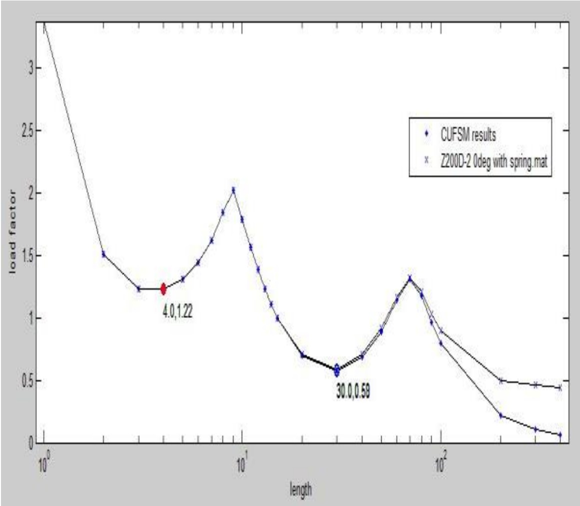

Figure 7: Z200D2 Buckling curve with rotational spring and excluding rotational spring

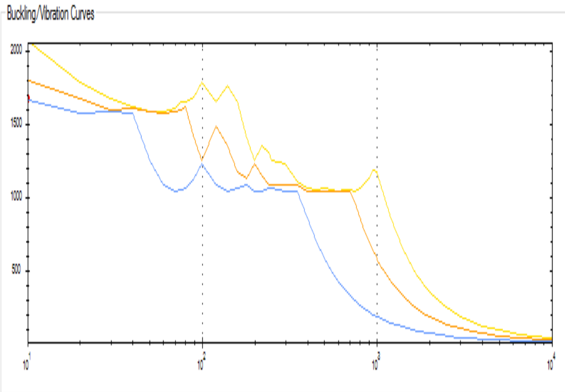

Figure 8: Z200D2 Buckling curve-GBTUL

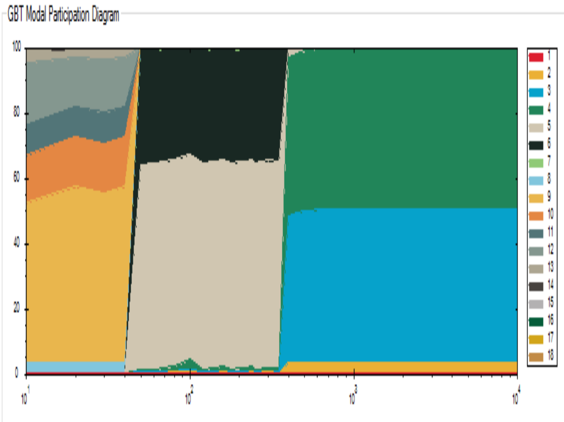

Figure 9: Z200D2 Modal Participation Diagram-GBTUL

3. RESULTS AND DISCUSSION

As from the analytical study it is evident that inclusion of rotational restraint resulted in increase of section capacity for the same cross section and orientation. For girts, the half wave length obtained from CUFSM used to interpolate buckling load from GBTUL in order to correlate the buckling behaviour at same length. Including rotational restraint in girts results in increase of strength in global buckling mode almost several folds of rotationally unrestrained girt sections. Section Z200D2 shown capacity increase of global buckling strength from 1.74KNm to 16.42KNm. Most of the girt section showed enhanced strength. In case of purlins orientation of purlins included as a prime factor for analytical study and roof angle range fixed from practical existing structures from 10 degrees to 26 degree 30minutes. In this parametric study 10 degree and 15 degree were taken as orientation of purlins and showed enhanced strength compared to flat placed purlin section. As purlins are generally placed inclined based on roof angle which also changes based on type of truss, it is found orientation also influence capacity and buckling mode of purlin sections. From the analytical result capacity of sections increase by 20% when orientation changes positive in CUFSM and strength not enhanced in GBTUL. Orientation changes in purlin specimens while analyzing in GBTUL some sections showed local buckling in top flange instead bottom causing strength reduction.

4. FUTURE WORK

As of now 10 specimens were analyzed using CUFSM and GBTUL software for Behaviour study under influence of rotational restraint on capacity of cold formed steel purlins and girts and influence of roof angle. In further work another 20 specimens with different boundary condition are to be analyzed and conclusion to be arrived after comparing analytical results with values from experimental study and codal provisions as well.

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