Response Analysis of Cold-Formed Dimpled Column

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Abstract – *Dimpled steel sheets are formed from plain mild steel sheets by the UltraSTEEL cold-roll forming process developed by Hadley Industries plc. UltraSTEEL is a cold rolled forming process that locally work hardens the base metal. During the forming process, both geometry and mechanical properties are considerably altered. The strength of dimpled steel sheets are significantly greater than those of the original plain steel sheets due to work hardening developed throughout the forming process. Hence, a number of advantages can be achieved by altering plain surface steel column to a dimpled surface steel column.*

In this study, the behaviour of plain and dimpled columns of circular cross-sections has been compared using ANSYS. The response of the dimpled steel column has been analysed under lateral impact and axial compressive load. A further investigation on the energy absorption characteristics of dimpled column under lateral impact is carried out.

Key Words: UltraSTEEL, Cold-Formed Dimpled Column, Work Hardening, Specific Energy Absorption, Lateral Impact.

I. INTRODUCTION

Hollow tubular members are widely used in many infrastructures. It has been identified in some previous researches that hollow tubular members are prone to transverse impact loading. Past research and statistic data have revealed that accidental collision is one of the main causes of structural failure. During the collision, the structural components are exposed to the operating axial compressive load as well as the lateral impact loads. The collision energy is absorbed by the tubular members subjected to bending conditions. In recent years, there is a particular interest in improving the resistance of tubular members to lateral impact loads and also improving the crashworthiness of thin-walled structures from different angles. Some studies focused on thin-walled columns with innovative cross-sections. By contrast, some studies focused on columns made of high strength materials, or filled by different materials such as concrete, foam or metal honeycomb core. Although different strategies have been studied to improve the energy absorption performance of structural members subjected to lateral impact loads, all those studies were limited to columns with plain surfaces, and the effects of introducing concave-convex geometry on the surfaces have not been previously investigated. The cold roll forming process is the progressive forming of steel strip into a desired section by passing through a series of rolls, arranged in tandem. It is generally the most economical method of manufacturing sections. The optimum economic viability in manufacturing industry requires a minimization of the amount of material used while the structural performance of roll-formed products relies on maintaining the stiffness and strength of the section. Additional bends introduced into the section such as ‘intermediate stiffeners’ can be a solution for these conflicting requirements. They have been found to improve the material properties of the finished product as the yield and tensile strength of the material increases within the deformed zone around the bends. However, such improvements are limited. An alternative mechanism to improve the material and structural performance is to impart a deformation to the whole sheet.

2. DIMPLED COLUMNS

Dimpled steel columns are formed from plain mild steel sheets by the UltraSTEEL® cold-roll forming process developed by Hadley Industries plc. In this forming process, plain mild steel coil is progressively fed into a pair of rollers with rows of specifically shaped teeth and formed into dimpled steel sheets, as shown in Fig. 1. Dimpled sheets are then formed into desired profiles by passing through a series of rolls or press braking. Several previous numerical and experimental research has revealed that the strengths of dimpled steel sheets are significantly greater than those of the original plain steel sheets. The increase in strength is mainly due to work hardening developed throughout the forming process. Fig. 2 shows plain column and dimpled column.

The main objectives of the study are:

- To analyse both plain and dimpled columns of circular cross-sections under axial compressive load.
- To study the response of dimpled column under both lateral impact and axial compressive load.

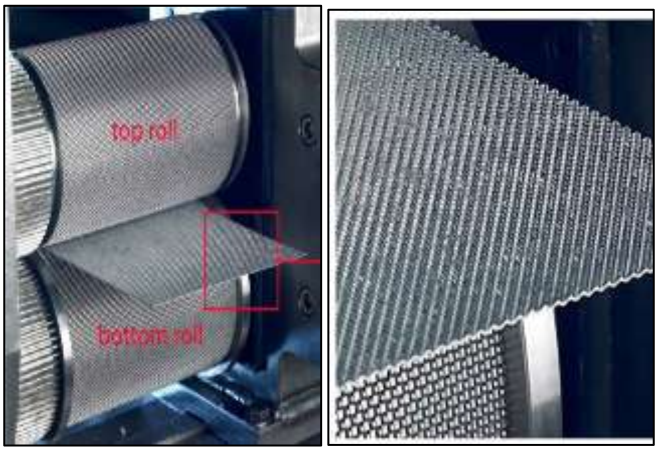

Fig-1: The Ultrasteel® Forming Rollers and Dimpled Steel Sheet

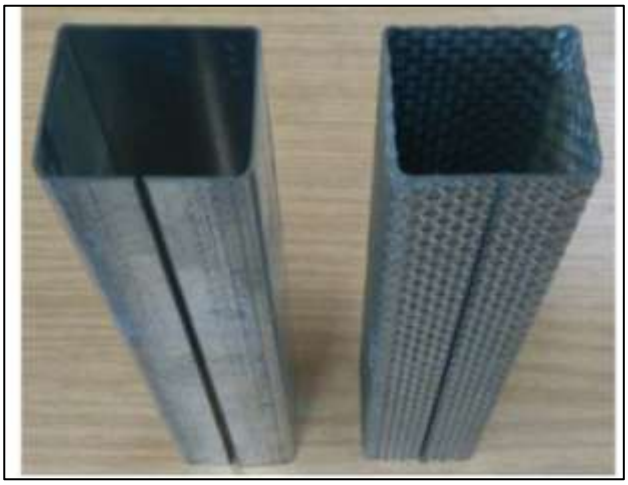

Fig-2: Plain Column and Dimpled Column

3. METHODOLOGY

- Planning stage
- Validation
- Modelling and Analysis of dimpled column
- Result and Interpretation

4. MODELLING OF STRUCTURE

4.1 Material Properties

The material's mechanical properties were obtained from quasistatic tests, following the appropriate British Standard [2] which is shown in Table 1.

Table-1: Material Properties

	Plain Column	**Dimpled Column**
Young's Modulus, E (GPa)	205	205
Poisson's Ratio	0.3	0.3
Engineering Yield Strength, σy,eng (MPa)	278	325
Engineering Ultimate Strength, σu,eng (MPa)	368	401

4.2. Dimensional Details

The circular hollow section (CHS) columms are adopted in this study. The dimensional details of plain column and dimpled column are shown in Table 2.

Table-2: Dimensional Details

Length of circular column	500mm
Diameter of circular column	37.5mm
Thickness of plain column wall	1 mm
Thickness of dimpled column wall	0.90 mm
Size of dimples	2.5mm

4.3. Modelling

1) Circular Plain and Dimpled Column under Axial Load

The thickness is 1mm for plain column walls and 0.90mm for dimpled column walls, due to the stretched surface after the forming process. To obtain the geometric model of the dimpled plates, the UltraSTEEL® forming process was firstly simulated using Ansys Workbench, based on a small square plate with symmetric boundary conditions applied, as described in [24]. The resultant nodal coordinates were exported to construct the generic geometric model of dimpled plates. The geometric models of the dimpled columns were then created by patterning the generic dimpled models.

A curved steel strip is placed in a pre-defined position between the top and bottom rolls to get a curved dimpled sheet. By symmetry, the curved sheet is transformed fully to a circular column.

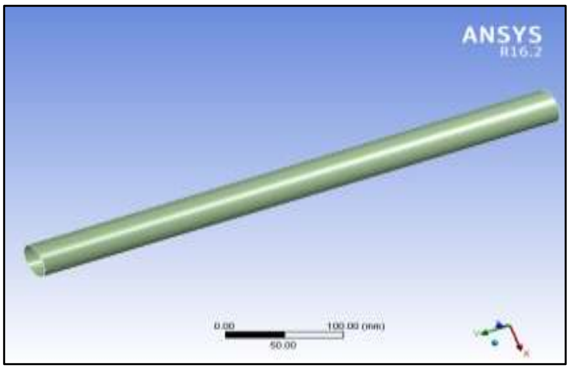

Fig-3: Plain Column

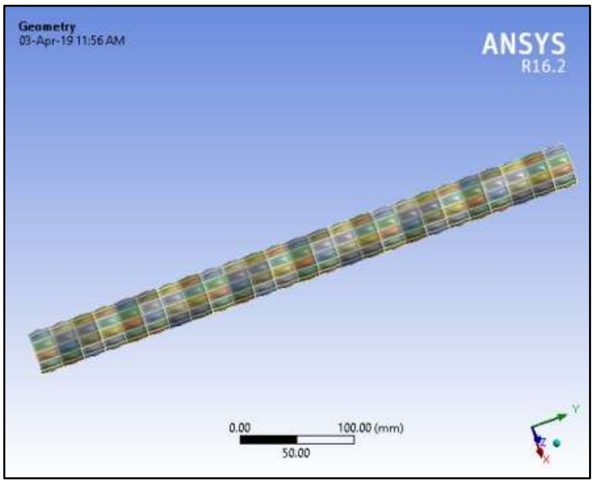

Fig-4: Dimpled Column

The external loads were applied in two stages. In the first stage, a quasistatic constant axial compressive load was applied on the one end of column while the other end is fixed. When selecting the axial compressive loads, it was ensured that the column did neither buckle nor yield solely under the axial compressive load.

2) Dimpled Column under Combined Axial Compressive and Lateral Impact Loads

The impact mass was constructed using 8-node solid elements. The columns were modelled using full-integration 4-node shell elements with five integration points throughout the thickness. In the second stage, a 0.1884 kg impact mass with an initial velocity of 4 m/s along y-axis was applied. The indenter was considered as a rigid body and translational DOFs of the impact mass were constrained along x and z directions, in order to represent the impact mass sliding along a straight trajectory. An axial compressive load of 6kN is applied at one end of the column.

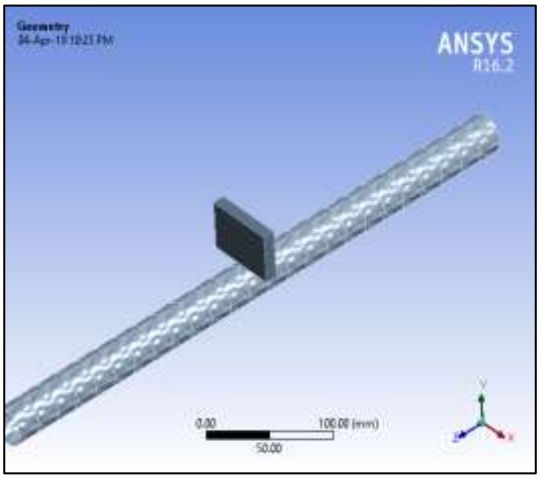

Fig-5: Dimpled Column under lateral impact

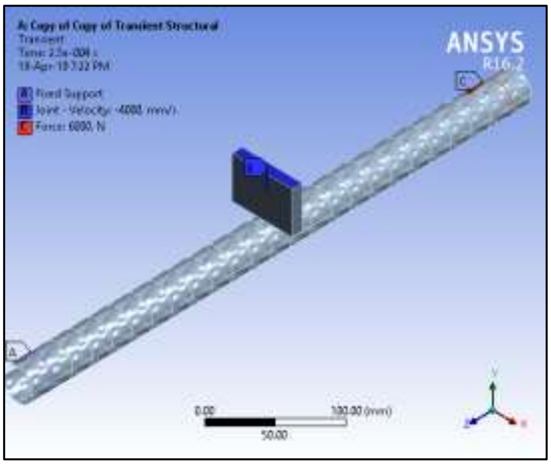

Fig-6: Boundary Conditions

5. ANALYSIS OF STRUCTURE

5.1 Circular Plain and Dimpled Column under Axial Load

Static structural analysis is carried out using ANSYS. The deformed shape of plain column and dimpled column are shown in Fig. 7 and Fig. 8.

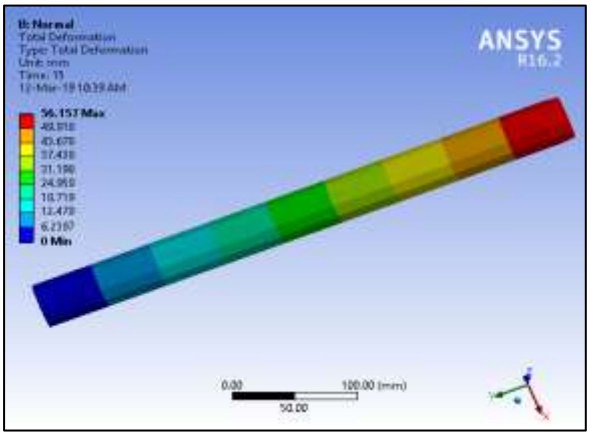

Fig-7: Deformed Shape of Plain Column

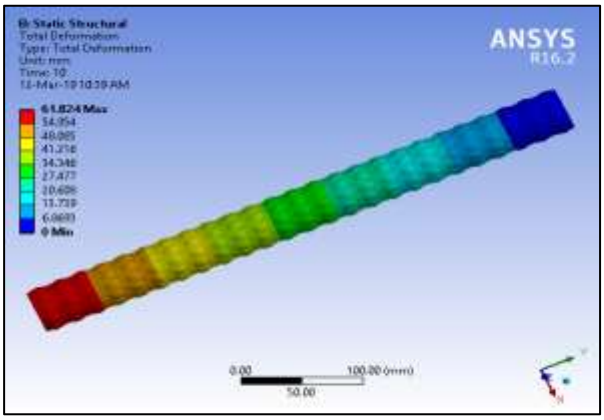

Fig-8: Deformed Shape of Dimpled Column

5.2 Dimpled Column under Combined Axial Compressive and Lateral Impact Loads

The explicit dynamics finite element code integrated in ANSYS Workbench 16.2 was employed to simulate the plain and dimpled steel columns' response to lateral impact loads. This explicit dynamics FE code is commonly used to deal with non-linear simulations involving complex contact interactions.

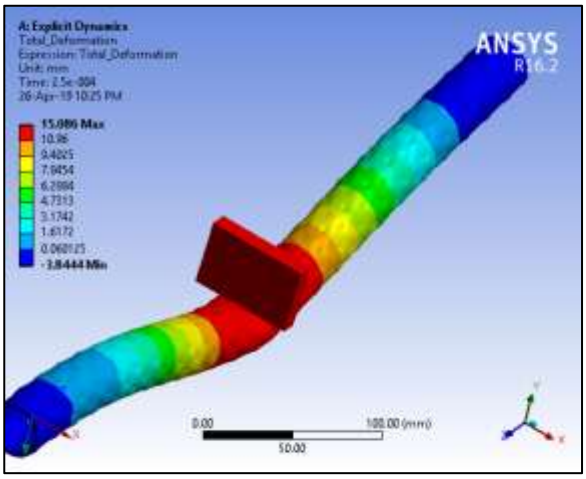

Fig-9: Deformation in Dimpled Column after lateral impact

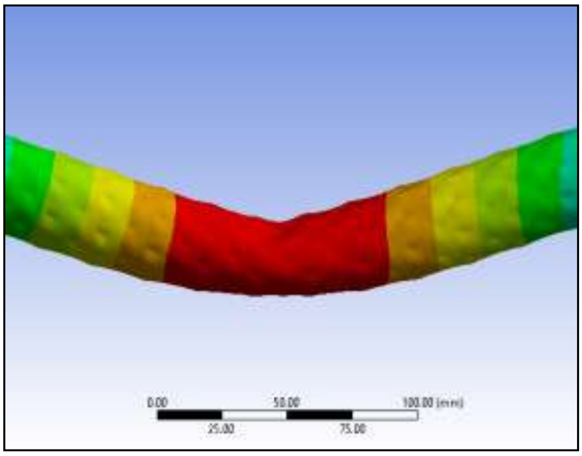

Fig-10: Maximum Deformation at the Centre of the Column

In the FE simulations, the automatic node-to-surface contact function was used to compute the contact between the indenter and the column, and the trajectory detection method was used. Symmetric boundary conditions were applied to the FE model along the axial direction.

6. RESULTS AND DISCUSSIONS

6.1 Circular Plain and Dimpled Column under Axial Load

The load – deformation curve of plain and dimpled column under axial compressive load is shown in Fig. 10.

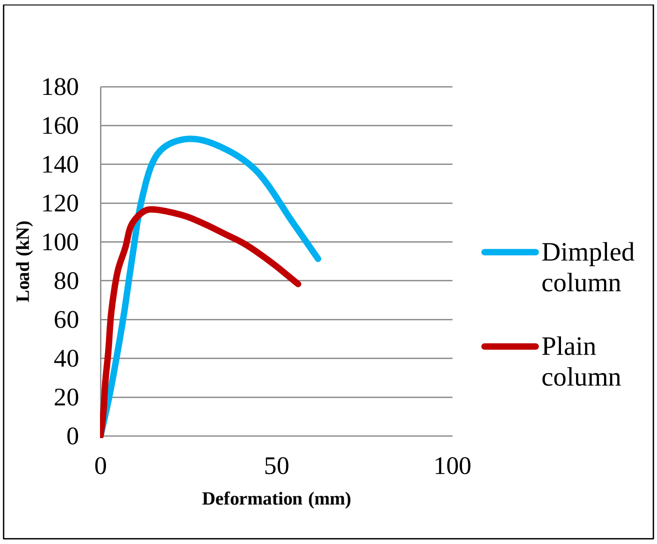

Fig-11: Load Deformation Curve of Plain and Dimpled Column

Tab-3: Ultimate Load Carrying Capacity

Material	Ultimate Load (kN)	Deformation (mm)
Plain Column	116.65	15.791
Dimpled Column	152.77	23.278

From Table 3, it can be seen that the ultimate load carrying capacity of dimpled column is 24% greater than that of plain column. That means they are capable of carrying greater compressive load than the plain column of same cross-section. It is clear that the cold work resulting from the dimpling process produces a significant increase in the ultimate strength of the dimpled column. During the dimpling process, work hardening is developed, which has caused an increase in the equivalent yield strength of the dimpled column.

6.2 Dimpled Column under Combined Axial Compressive and Lateral Impact Loads

Fig. 12 shows the impact force vs time graph of dimpled column under both lateral impact load and axial compressive load.

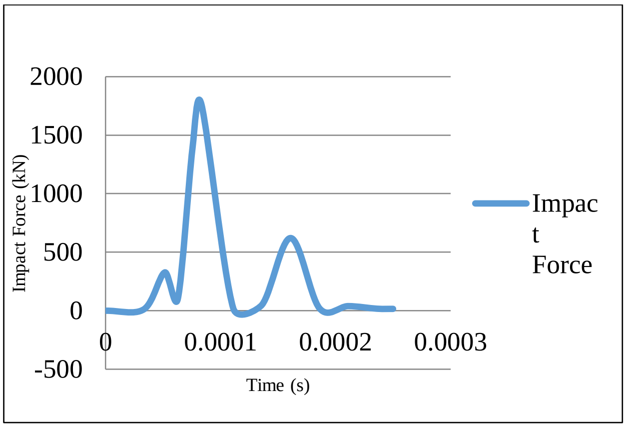

Fig-12: Impact Force vs Time Graph of Dimpled Column

The maximum impact force obtained for dimpled column from the graph is 1762.64 kN which is also the second peak force in the graph. The 1st peak force appears when the contact between impactor and column starts. The 2nd peak force which is also the maximum impact force appears while buckling around the impact location is being developed.

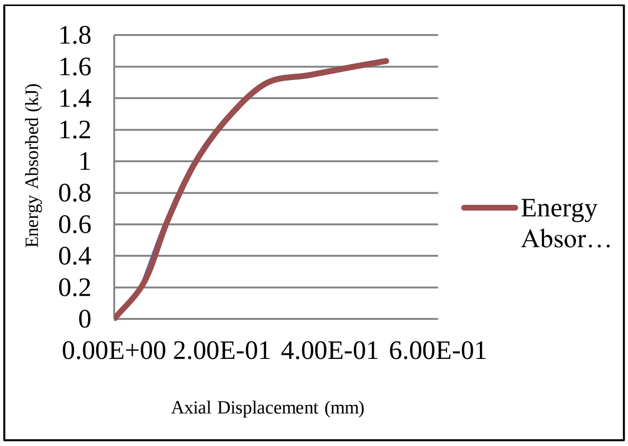

Fig-13: Energy Absorbed vs Axial Displacement curve of Dimpled Column

The energy absorbed (EA) – axial displacement curve is shown in Fig. 12. In this, specific energy absorption (*SEA*) was employed as the primary index to evaluate the energy absorption performance. *SEA* is calculated based on the effective crushing distance and it is defined as Eq. (1), where δ represents the axial displacement, P represents the impact force, and m represents the mass of the column.

$$\text{SEA} = \frac{\int_0^{\delta total} P d\delta}{m} = \frac{EA\ per\ unit\ length\ of\ axial\ displacement}{Mass\ of\ column\ per\ unit\ length} \qquad (1)$$

In Eq. (1), the term '*EA per unit length of axial displacement*' equals to the gradient of Energy absorbed – axial displacement curve, while the term '*Mass of column per unit length*' is a constant, i.e. 0.1884kg. The linear fitting method was carried out in order to determine the term '*EA per unit length of axial displacement*'.

Therefore, on solving the Eq. (1), we get specific energy absorption (SEA) of dimpled column as 17.17kJ/kg which shows a better response under low- velocity axial impact loads.

7. CONCLUSION

From the analysis it is clear that the ultimate load carrying capacity of dimpled column is 24% greater than that of plain column. They are capable of carrying greater compressive load than the plain column of same cross-section. During the dimpling process, work hardening is developed, which has caused an increase in the equivalent yield strength of the dimpled column. From the impact analysis of dimpled column, the maximum impact force obtained is 1762.64kN. The specific energy absorption capacity of dimpled column which is calculated from the energy absorbed-axial displacement curve is 17.17 kJ/kg, which is a good result for low- velocity axial impact loads.

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