

Ultimate Strength Analysis of Highly Damaged Plates

Jyothy K George, Jobil Varghese,

Abstract—Thin plate structures are efficient structures because of their high load-carrying capacity and small weight. Thin plates are one of the common structural elements. Their load-carrying capacity mainly depends on their buckling behavior, which is in turn affected by the imperfections present in them. Dent is one of the common geometrical imperfections in thin shell structures, which may be formed in the plate as an impact of sharp objects, among other reasons. This work deals with the ultimate compressive strength of highly damaged plating resulting from dropping objects, grounding or collision. Extensive static nonlinear finite element analyses were conducted using ANSYS. The effect of dent depth as well as dent size were studied. Different dent shapes are considered in order to cover different possible damage scenarios.

Index Terms—Ansys, Dent, Finite element analysis, Plate, Ultimate strength,

1 INTRODUCTION

STEEL plate structural components are the main structural components of ocean structures; ships, platforms and floating docks. As a result of the operating conditions, different damage scenarios may occur, including corrosion degradation, crack growth and indentation related to large plastic deformation. Each damage scenario affects the capacity and integrity of structures in a different manner.

Due to the operational conditions, the ship structural components are subjected to different damage scenarios accounting for corrosion degradation and fatigue cracking. As a result of dropping objects, collision and grounding, local dents may be formed. All of these types of damages directly affect the structure, which in turn influences the load carrying capacity of the structure and its ultimate strength.

For collision, damage may occur due to interaction between two ships, ships and offshore structures, ship and quay side or a ship-ice contact. Normally the most affected structural areas are the side shell (plating, frames and stringers) and bow. Consequently, the damage locations and shapes are different around the ship hull and depend on the operational conditions and the geometry of the indentation object. In case of dropped objects, which normally happened on the ship deck or platforms, the indentation is formed due to falling down of an object i.e. containers or equipment.

In this regard, the primary contribution of the present study is to investigate the ultimate compressive strength reduction characteristics for steel plates due to local denting. It is expected that the effect of denting on the plate buckling collapse behaviour may vary from shape and size of the dent, and thus a series of ultimate strength analyses varying such parameters are in this paper carried out using ANSYS nonlinear finite element method.

2 GEOMETRIC IDEALIZATION OF DENTING DAMAGE

The geometry descriptors of the analysed plates are shown in Fig. 1 and Table 1, where 'a' is the plate length, 'b' is the plate width, t_i is the plate thickness. The dent geometry is shown in Fig. 2, where l_i is the dent length, s_i is the dent width, L_{Di} is the local dent depth, S_{Hi} is the dent shape, where three shapes are identified as H for the hemisphere, C for cubic and P for prismatic shape, respectively.

The material used in the finite element model was of low carbon steel with the yield stress, σ_y of 290 MPa, the Young modulus, E of 206 GPa and the Poisson's ratio, ν of 0.3 and the stress-strain model is elastic-perfectly plastic. The analysed plates are subjected to uniaxial compressive load. The applied boundary conditions are shown in Fig. 1.

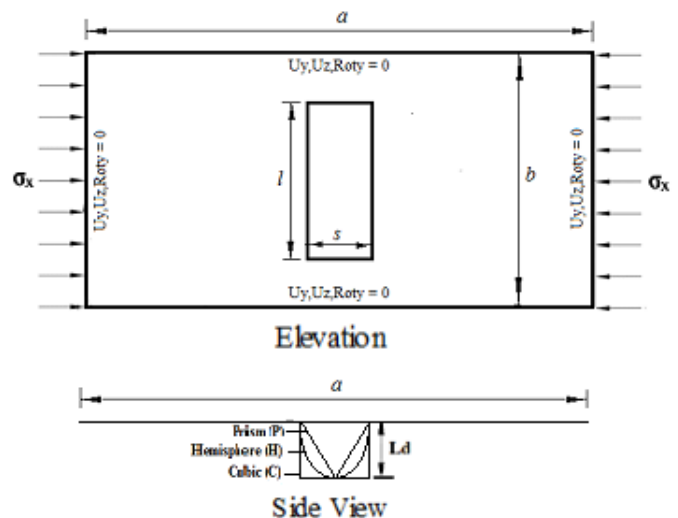


Fig. 1. Plate dent configurations, location and the applied boundary conditions

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TABLE 1
STRUCTURAL CONFIGURATIONS OF PLATE.

Plate mensions (mm)	di- (mm)	ti (mm)	LDi (mm)	Si(li,si) (mm)	SHi	
a	800	t ₁	4	LD1 0	S1 200,100	SH1 H
b	400	t ₂	10	LD2 4	S2 250,100	SH1 C
		t ₃	12	LD3 8	S3 350,100	SH1 P
		t ₄	16			

3 FE MODELLING

The ultimate strength analyses of dented plates are performed based on the finite element method employing a general nonlinear finite element commercial code ANSYS.

The entire finite element model is generated using the shell element SHELL 181, which is defined by four nodes, with six degrees of freedom at each node: translations in the x, y, and z directions, and rotations about the x, y, and z-axes. Shell 181 is well-suited for linear, large rotation, and/or large strain nonlinear applications and suitable for analysing thin to moderately-thick shell structures.

Extensive static nonlinear finite element analyses are performed. Having activated the large strain option, it encompasses the shape change of the elements (i.e., strains are finite), rigid-body effects (e.g., large deformation), stress stiffening and regular linear analysis to solve the geometric and material nonlinearities and to pass through the extreme points. The automatic time stepping features are also employed, allowing to determine appropriate load steps.

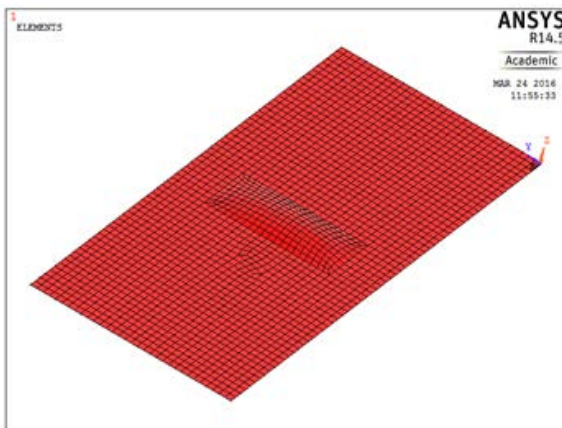


Fig. 2. Finite element model of plate with dent.

The material used in the finite element model was of low carbon steel with the yield stress, σ_y of 290 MPa, the Young modulus, E of 206 GPa and the Poisson's ratio, ν of 0.3 and the stress-strain model is elastic-perfectly plastic.

The quadrilateral element size of 5 mm has been defined as a good solution of the finite element model. The analysed plates are subjected to uniaxial compressive load. The applied boundary conditions are shown in Fig. 1.

4 FE ANALYSIS

The finite element studies presented here relate to the parameter variation as given in Table 1. Three groups of analyses are conducted as described in Table 2. In the first one, the effect of dent depth (LD) is studied for three plate thicknesses, exploring the effect of dent depth on different thicknesses. In the second group, the variation of the dent size, S for two thicknesses and its influence on the ultimate compressive strength is investigated. In the third group, the structural responses of the plate for different idealized dent shapes SH, dent depths and plate thicknesses are presented and discussed.

TABLE 2
FE ANALYSIS GROUPS

Item	t		LD
Group 1 (LD)	t ₁		LD1
	t ₂		LD2
	t ₄	S3U	LD3
		SH1	
Group 2 (S)	t ₁	SH1 U {S1, S2, S3}	
	t ₂		LD3
Group 3 (SH)	t ₁	{SH1, SH2, SH3} U {S1, S2, S3}	
	t ₂		LD1
	t ₃		LD2
	t ₄		LD3

4.1. Dent depth effect

The effect of the local dent depth, LD on the global structural behaviour and the ultimate compressive strength of rectangular plates with different thicknesses of 4, 10 and 16 mm is presented here. One dent size, S3 with hemisphere dent shape, H is used to model the damage shape in the nonlinear finite element analysis. The normalised stress-strain relationships for the considered thicknesses are shown in Figs. 5, 6 and 7. The normalized strength is calculated by dividing the plate strength (σ) to the material yield stress (σ_y) and the normalized strain is calculated by dividing the plate strain (ϵ) to the material yield strain (ϵ_y).

The Von Mises stresses for an intact and dented plate with LD3 is presented in Figs.3, 4 and 5. For the intact one (see Fig. 3), as the plate thickness increases, the spread of the highly stressed zone increases. With the presence of the dent (see Figs. 4 and 5), the highly stressed area in the thick

plate (16 mm) decreases and is concentrated only in the central part, this is because the dent borders act as local hinges and there is no flexibility to deform far away from the dent location. This is in a contrast to what occurred in the thinner plates, where the highly stressed areas are concentrated in the central zone and in some locations around the unloaded edges.

Fig. 3. Von Mises stresses for intact plate.

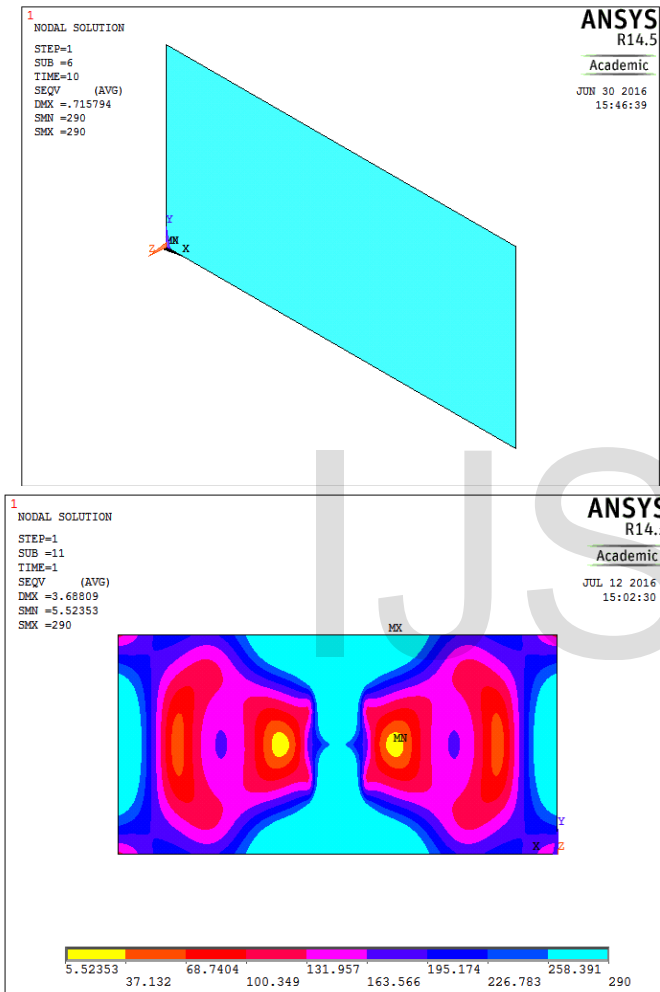


Fig. 4. Von Mises stresses for platethickness 4 mm

The Von Mises stresses for an intact and dented plate with LD3 is presented in Figs.3, 4 and 5. For the intact one (see Fig. 3), as the plate thickness increases, the spread of the highly stressed zone increases. With the presence of the dent (see Figs. 4 and 5), the highly stressed area in the thick plate (16 mm) decreases and is concentrated only in the central part, this is in a contrast to what occurred in the thinner plates, where the highly stressed areas are concentrated in the central zone and in some locations around the unloaded edges

Fig. 5. Von Mises stresses for plate thickness 16 mm

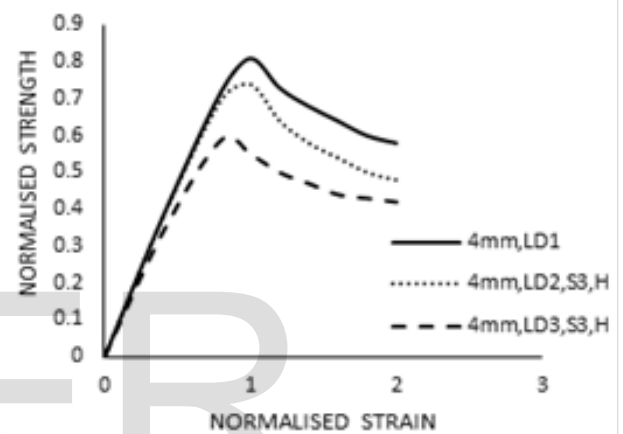
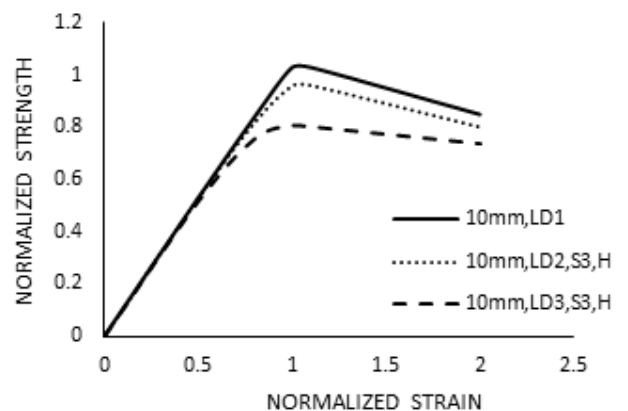
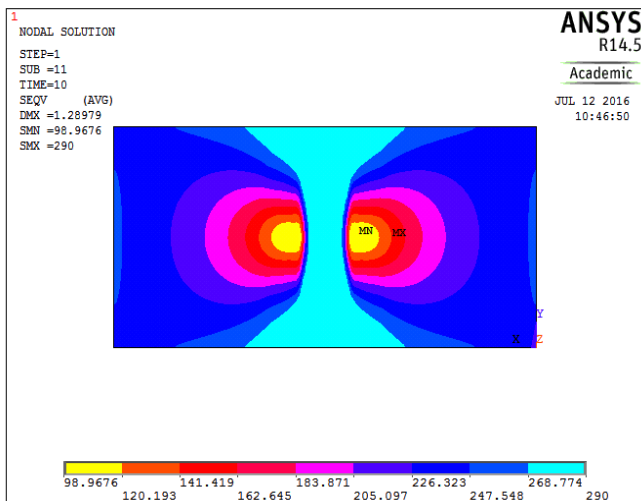


Fig. 6. Normalised stress-strain, t = 4 mm, different dent depth

Fig. 7. Normalised stress-strain, t = 10 mm, different dent depth



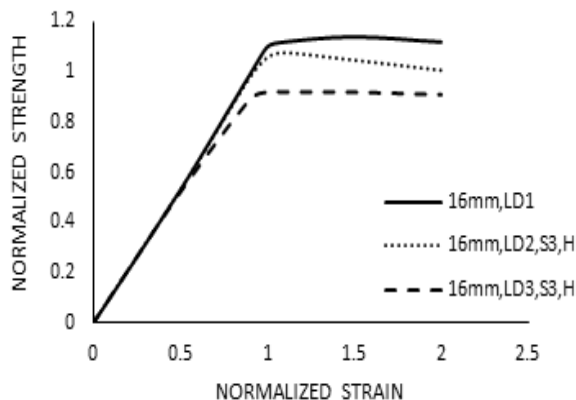


Fig. 8. Normalised stress-strain, $t = 16$ mm, different dent depth

From Figs. 6, 7 and 8, for a plate without a dent, LD1 (intact), as the plate thickness increases, the ultimate strength increases. By increasing the plate thickness from 4 to 10 and 16 mm, the deviation in the post-buckling regime decreases. By increasing the dent depth to LD3 (8 mm), the reduction of the ultimate strength is greater than the one of LD2 (2 mm). For a 4 mm plate thickness, with LD3 there is a noticeable deviation in the buckling and post-buckling behaviour, which only can be observed in post-buckling regime for LD2. This indicates that for a thin plate, the increase of the dent depth affects both buckling and post-buckling, which in turn significantly decreases the ultimate strength.

4.2. Dent size effect

It can be seen from Figs. 9 and 10 that for a thin plate of 4 mm, when the dent size is increased, the estimated ultimate strength decreases. By increasing the plate thickness up to 10 mm, the reduction in the ultimate strength, due to the variation of dent size, is less than the one of 4 mm. Comparing the strength curves of 10mm and 4mm thicknesses in Figs. 8 and 9; it is visible that the one of a 10 mm thickness has a less deviation than the one for a 4 mm thickness, with respect to the intact one. This indicates that as the plate thickness increases, the effect of dent sizes on reducing the plate stiffness decreases.

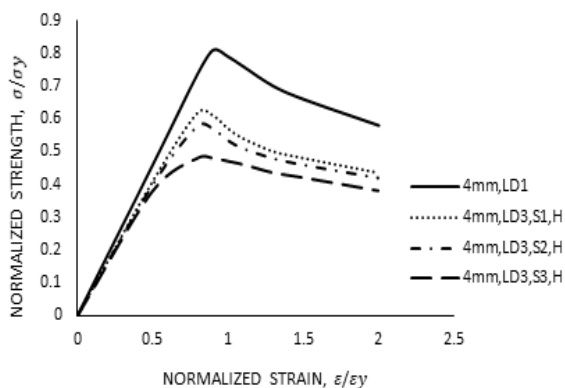


Fig. 9. Normalised stress-strain, $t = 4$ mm, different dent size for a hemisphere dent shape (H).

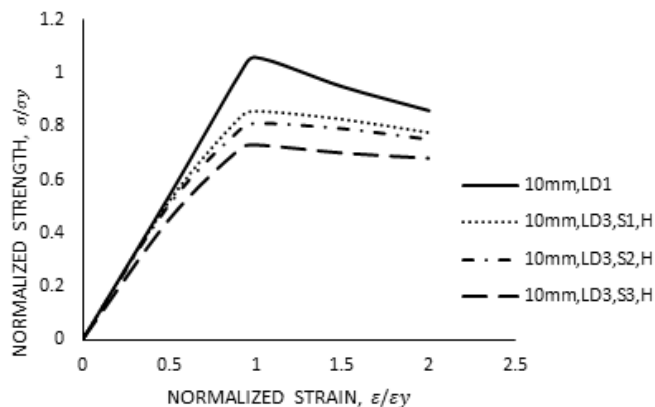


Fig. 10. Normalised stress-strain, $t = 10$ mm, different dent size for a hemisphere dent shape (H).

4.3. Dent shape effect

Three different dent shapes are considered in the following analysis named as H for the hemisphere, C for cubic and P for prismatic shape with a dent depth of LD3 (8 mm) and dent size S3. The effect of these shapes on the local and global structural behaviour of plates is investigated. The results of the normalized stress-strain relationships for three selected thicknesses 4, 10 and 16 mm are presented in Figs. 12, 13 and 14.

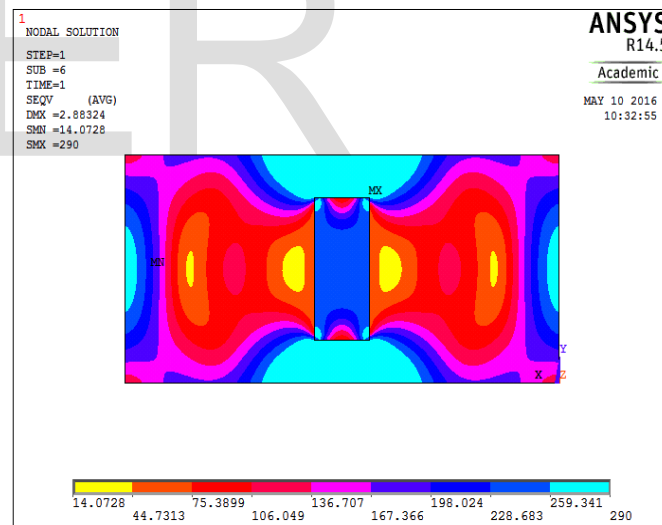


Fig. 11. Von Mises stresses for cubic dent (thickness 4 mm)

By increasing the plate thickness from 4 to 10 mm, the reduction of the ultimate strength as a result different dent shapes are less than for the one for a 4mm plate thickness compared to the ultimate strength of the intact plate.

Also, for a 10 mm plate thickness, (Fig. 13), the deviation in the normalized strength curve for all the dent shapes is less than for the ones observed for a 4mm plate thickness. This indicates that the effect of different dent shapes on the plate stiffness is less for thicker than for the thinner ones.

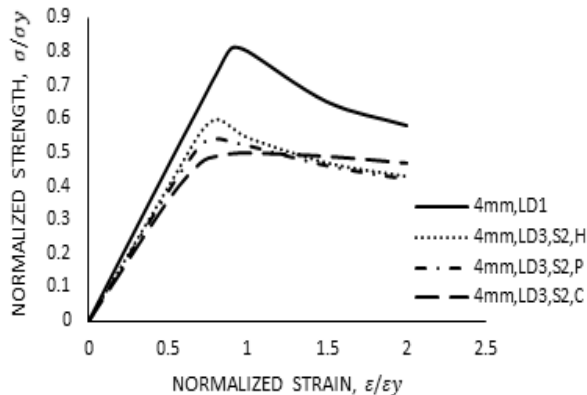


Fig. 12. Normalised stress-strain, $t = 4$ mm, different dent shapes.

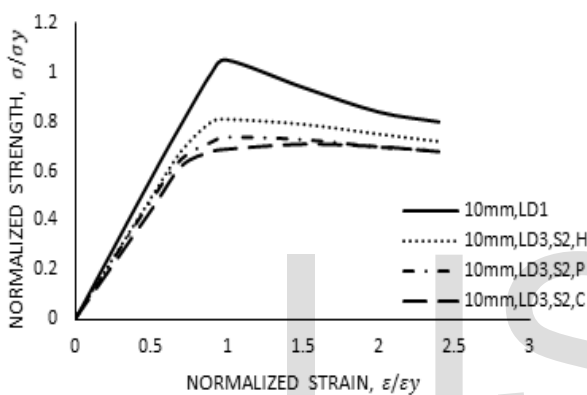


Fig. 13. Normalised stress-strain, $t = 10$ mm, different dent shapes.

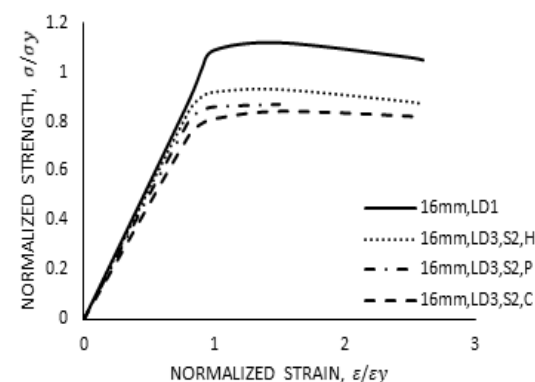


Fig. 14. Normalised stress-strain, $t = 16$ mm, different dent shapes.

For a thick plate of a 16mm plate thickness, as the dent size increases the variation of the ultimate strength between the hemisphere, H and the other two shapes C and P increases compared to the one of a 4 mm plate thickness.

Based on the conducted analyses of the ultimate strength accounting for different dent shapes, the cubic shape, C presents the lower ultimate strength for all thicknesses as well as for all considered dent sizes.

5. CONCLUSION

An ultimate strength assessment of highly damaged steel plates with a permanent local indentation has been carried out, using a static nonlinear finite element analysis. The effect of the dent depth as well as dent size is investigated. The behaviour of the dented plate is analysed accounting for three dent shapes.

It was observed that the reduction of the ultimate strength in the presence of dent decreases as the plate thickness increases.

More energy needs to be absorbed to reach the collapse of thin plates with a deep dent; this is because the dent is acting as a resisting spring. On the contrary, for a small dent depth, the plate collapsed with a great discharge.

In the range of the analysed plate thicknesses, the cubic dent shape, C decreases much more the ultimate strength rather than the dent shape H.

Also, the dent size has insignificant effect on the reduction of the stiffness as the plate thickness increases. It may also be concluded that, from the strength point of view, in the case of a dent resulting from collision, grounding or dropped objects, the repair or replacement of the damaged area is not necessary to be done if the dent depth is very large.

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