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ITJ

ISSN 1812-5638

INFORMATION TECHNOLOGY JOURNAL

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Information Technology Journal 12 (24): 8212-8219, 2013
ISSN 1812-5638 / DOI: 10.3923/itj.2013.8212.8219

Displacement Analysis and Comparison of Lateral and Axial Typical Dent on Pipeline Based on FE Calculation

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Abstract: Dent, which is one of the important factors affecting pipeline fatigue life, substantially reduces the fatigue life of the pipeline in service. Meanwhile, the dent displacement will be changed with the operation pressure fluctuations of the in-service pipeline, resulting in a circular bending stress, which directly affect the pipeline fatigue life. Finite element models of typical lateral and axial dent were established under different circumstances. On the basis of considerable calculations, the results were subjected to univariate and multivariate analyses, yielding the dependences of displacement on different parameters. The calculation results were fitted by non-linear regression. The relationships between the maximum displacement of two kinds of typical dented pipeline and the dent depth, diameter and thickness of pipeline and the dent longitudinal length were acquired by establishing mathematical models. And the characteristics of the displacement variation and mathematical model of typical lateral and axial dent were obtained.

Key words: Lateral dent, axial dent, displacement, finite element method

INTRODUCTION

Maintaining a high level of pipeline integrity and reliability of oil and gas industry is very important. It has been reported by the United States Transportation Department that mechanical damage is one of the most critical reasons accounting for pipeline accidents, in which indentation (or simply dent) is most typical. The Fig. 1 is dent cross-section shape (Noronha *et al*., 2010; Wu *et al*., 2013a).

In order to avoid pipeline accidents and prolong the pipeline operation life, many standards were made in foreign. These standards such as Canada pipeline design standard made by Canadian Standards Association, ASME B31.4 and ASME B31.8 all require the dent depth less than 6% of the pipe diameter (Rinehart *et al*., 2002; Allouti *et al*., 2012; Wu *et al*., 2011).

Dent depth is one of important index, which determine whether the damaged pipeline should be repaired. But, only considering dent depth is not enough, dent length, pipe diameter and wall thickness are also important indexes (Wu *et al*., 2013; Hojjati and Lukasiewicz, 2008; Al-Muslim and Arif, 2011).

Under the effect of internal pressure, the dented pipe can have certain recovery, which will increase with the increase of internal pressure. Dent recovery can be described by the recovery ratio, which is the ratio of the ultimate dent depth that undergoes the dent recovery and the original dent depth after the external disturbance is removed. The dent recovery ratio is the very important parameter to influence the fatigue life of the dented pipeline. Numerous fatigue tests concerning typical dents have been performed hitherto (Allouti *et al*., 2012).

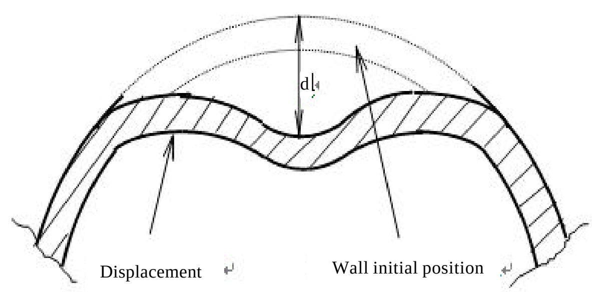

Fig.1: Typical dent cross-section shape

There is a direct correlation between the dent recovery and the maximum displacement when the dented pipeline suffered the operating pressure. In order to accurately evaluate the fatigue life of dented pipeline, the displacement was subjected to single-factor and multi-factor analyses by regression based on finite element calculation results.

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LATERAL AND AXIAL TYPICAL DENT MODELING

According to the data accumulated at the scene, the dents on pipeline can be classified into two typical dent: lateral and axial dent (Fig. 2 and 3). The finite element analysis is carried out in this paper.

Finite element software was utilized to establish the dented pipeline models under different circumstances. According to the real stress state and geometry shape of the pipe in the presence of internal pressure, half pipe including dent defects was selected by axisymmetric principle.

Apparently, boundary conditions affect deformation differently even at identical loads. However, compared to the dimension of pipelines, the dent in a pipe is so small that it can always be treated as a local deformation. Therefore, the pipe was set sufficiently long in the FE model (6 times longer than the outer radius of pipe) to generalize the research and maintain the impact of boundary conditions. In addition, the boundary conditions of both ends of the pipe were fixed to simulate the actual situation (Beak *et al*., 2012).

In fact, most dent defects are induced during construction, after which the external disturbance is eliminated. Thus, the FEM model only considers formed dents. Besides, the influence of internal pressure rather than that of external load is involved.

Foure-node shell element SHELL 63 was used to mesh the solid model. Different meshing densities were used to simulate the dent, from which the optimal one was selected according to the analytical process, calculation accuracy and time and etc (Limam *et al*., 2012). The FE models of lateral and axial dent are respectively in Fig. 4 and 5.

The model of the original dent originates, respectively from a small round stick compressing pipeline along the lateral and longitudinal (axial) pipe. The diameter and wall thickness of the pipe are D and t respectively. The longitudinal dent length of the FE model is L. Dent length is the distance between adjacent intact cross-sections on both sides of the dent. The dent depth of the FE model is d. Dent depth is the maximum displacement of the pipe wall thickness on the site of dent. The internal pressure of the FE model is P. The internal pressure is all equal to 3.45 Mpa for finite element computation. In addition, the finite element model conformed to some existing papers that study the similar problems.

Figure 6 and 8 are the deformation and displacement of lateral typical dent, respectively at 3.105 MPa. Fig. 7 and 9 are the deformation and displacement of axial typical dent respectively at 3.105 MPa. The ratio of pipe diameter to wall thickness (D/t) is 30 and the ratio of dent depth to pipe diameter is 0.08.

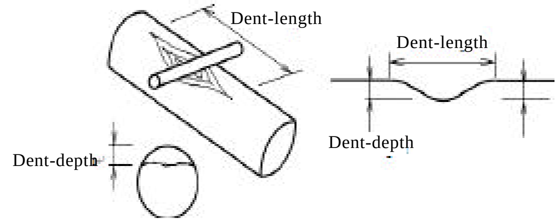

Fig.2: Shape of lateral typical dent

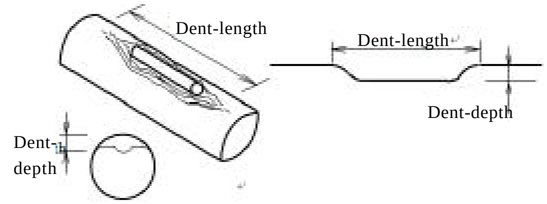

Fig.3: Shape of axial typical dent

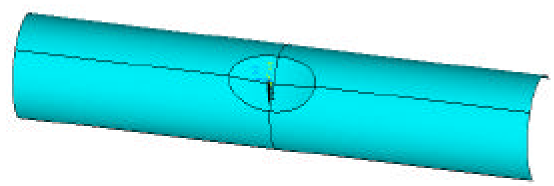

Fig.4: FE model of lateral typical dent.

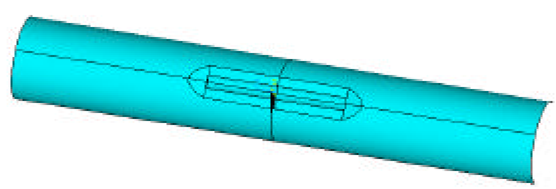

Fig.5: FE model of a typical dent

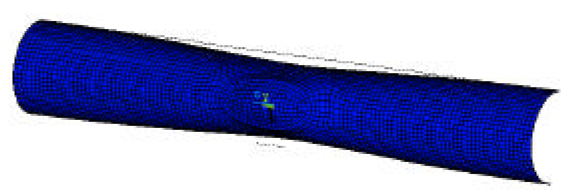

Fig.6: Deformation of lateral typical dent

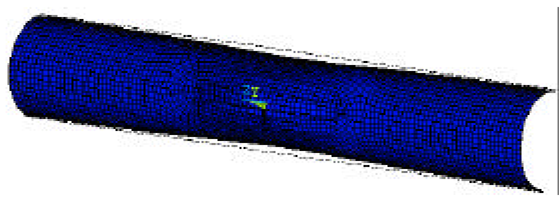

Fig.7: Deformation of axial typical dent

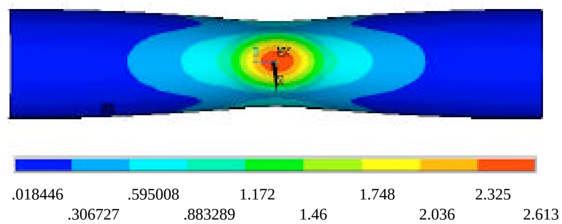

Fig.8: Displacement of lateral typical dent (mm)

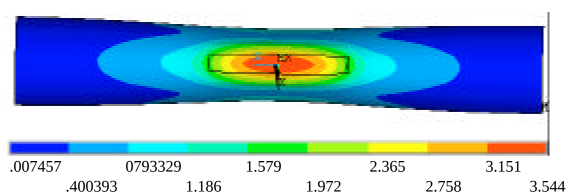

Fig.9: Displacement of axial typical dent (mm)

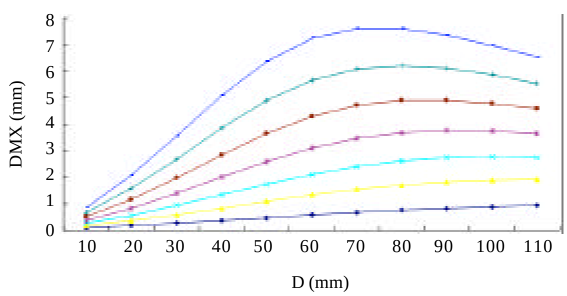

Fig. 10: Relationship of the maximum lateral typical dent displacement and dent depth

SINGLE FACTOR ANALYSIS OF DISPLACEMENT

Dent depth: Figure 10 and 11, respectively show the relationships between the two kinds of dent maximum displacement (DMX) and dent depth (d) in case of different ratio of pipe diameter and wall thickness (D/t) when the other parameters is unchanged. The values of D/t are, respectively 18, 20, 25, 30, 35, 40, 45, 50 from down to up in two figures.

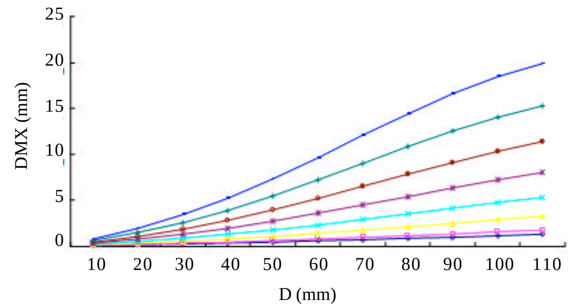

Fig.11: Relationship of the maximum axial typical dent displacement and dent depth

As can be seen from the above two figures, the variation of lateral typical dent is more complicated than axial. The change curve of lateral typical dent is more close to the parabolic curve and the axial one is more close to the straight line. This shows that the influence of dent type on the relationship between the displacement and dent depth is quite big.

As a whole, the maximum displacement is elevated with increasing dent depth. But when the values of D/t are more than 35, the maximum displacement of lateral dent increased first and then decreased with increasing dent depth. So, for lateral dent, the more D/t is big namely the more pipe tend to thin, the more change trend of maximum displacement with the dent depth variation is obvious. This is a very special characteristic.

When the other parameters remain unchanged, the relationship between the maximum displacement of lateral dent and dent depth can be expressed by the sine function model (Sine brackets for radian) below:

$$\text{DMX} = a\sin(bd + c) \qquad (1)$$

And the relationship between the maximum displacement of axial dent and dent depth can be expressed by the power function model below:

$$\text{DMX} = ad^{b} \qquad (2)$$

The Table 1 and 2, respectively list out the coefficients of Eq. 1 and 2 between the maximum displacement and dent depth under the different values of D/t.

The corresponding correlation coefficient square (R^2) of the expression in Table 1 are more than 0.9. The classification is according to the principle of fitting the

Table 1: Values of coefficients at different D/t

D/t	Coefficient a	b	c
(15,22)	1.211	0.618	3.182
(22,27)	1.971	0.615	22.069
(27,32)	2.794	0.613	3.245
(32,37)	3.787	0.646	31.299
(37,42)	4.947	1.238	3.266
(42,47)	6.261	0.608	9.550
(47,52)	7.726	0.607	3.263

Table 2: Values of coefficients at different D/t

D/t	Coefficient a	b
18	0.0029	1.3
20	0.0039	1.3
25	0.0072	1.3
30	0.0012	1.3
35	0.0179	1.3
40	0.0257	1.3
45	0.0351	1.3
50	0.0463	1.3

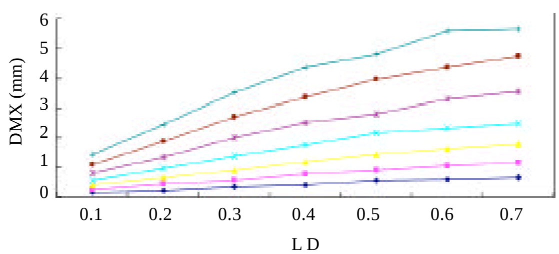

Fig. 12: Relationship of the maximum lateral typical dent displacement and L/D

best. And the corresponding correlation coefficient square (R^2) of the expression in Table 2 are more than 0.99, indicating a satisfactory fitting effect.

In addition, in Table 2, coefficient b which is equal to 1.3 is constant and only the values of coefficient a are increase with the increased of D/t. The coefficients can also be determined by the interpolation method when the D/t values fall out of those listed in Table 2 because D/t and the maximum displacement are linearly correlated.

Longitudinal dent length: Figure 12 and 13, respectively show the relationships between the two kinds of Dent Maximum Displacement (DMX) and the ratios of longitudinal dent length and pipe diameter (L/D) at different pipe diameter when the other parameters is unchanged. The values of D are, respectively 400, 500, 600, 700, 800, 900, 1000 (mm) from down to up in two figures.

As can be seen from Fig. 12 and 13, the maximum displacement is elevated approximately with increasing the values of L/D and the relationship between the

Table 3: Values of coefficients at different diameter

D (mm)	Coefficient a	b
400	0.0008	1.3262
500	0.0120	0.7828
600	0.0150	0.7956
700	0.0280	0.7302
800	0.0460	0.7361
900	0.0460	0.7235
1000	0.0530	0.7136

Table 4: Values of coefficients at different D/t

D (mm)	Coefficient a	b	c
400	2744.9	0.300	3.100
500	6.2200	0.001	6.261
600	3.7540	0.002	12.48
700	4.6460	0.002	6.190
800	5.7570	0.002	6.170
900	7.2830	0.002	6.164
1000	7.7260	0.607	3.263

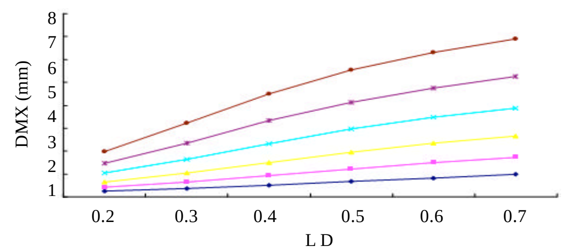

Fig. 13: Relationship of the maximum axial typical dent displacement and L/D

maximum displacement and L/D is closed to linear. In addition, the former changes less significantly with varied L/D at lower pipe diameter values and vice versa.

When the other parameters remain unchanged, the relationship between the maximum displacement of lateral dent and longitudinal dent length can be expressed by the found function model below:

$$DMX = aL^b \quad (3)$$

And the relationship between the maximum displacement of axial dent and longitudinal dent length can be expressed by the sine function model (Sine brackets for radian) below:

$$DMX = a\sin(bL + c) \quad (4)$$

The Table 3 and 4, respectively list out the coefficients of Eq. 3 and 4 between the maximum displacement and longitudinal dent length under the different values of L/D.

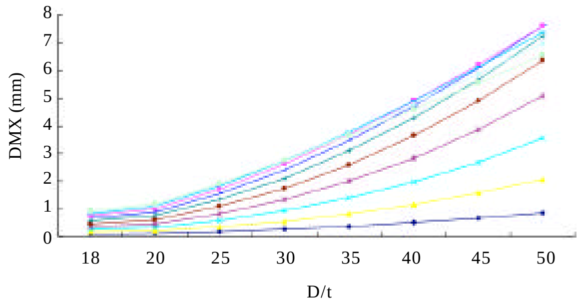

Fig.14: Relationship of the maximum lateral typical dent displacement and D/t

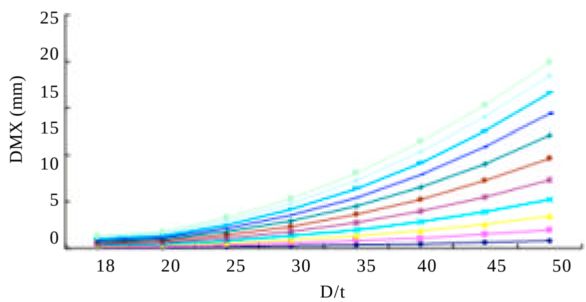

Fig.15: Relationship of the maximum axial typical dent displacement and L/D

The corresponding correlation coefficient square of the expression in Table 3 and 4 are all more than 0.98, indicating a satisfactory fitting effect. The coefficients can also be determined by the interpolation method when pipe diameter fall out of those listed in Tab. because pipe diameter and the maximum displacement are linearly correlated.

Pipe wall thickness: Figure 14 and 15, respectively show the relationships between the two kinds of dent maximum displacement (DMX) and pipe wall thickness (t) in case of different ratio of pipe wall thickness and diameter (d/D) when the other parameters is unchanged. The values of d/D are respectively 0.01, 0.02, 0.03, 0.04, 0.05, 0.06, 0.07, 0.08, 0.09, 0.1, 0.11 from down to up in two figures.

As can be seen from the above two figures, displacement change curves are all smooth curve and the maximum displacement is elevated with increasing the values of D/t. For axial typical dent, displacement variation is quite uniform with increasing D/t at different values of d/D. But, for lateral typical dent, displacement variation is reduced with increasing D/t at different values of d/D.

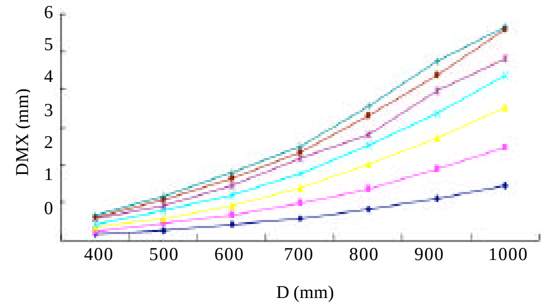

Fig.16: Relationship of the maximum lateral typical dent displacement and pipe diameter

Table 5: Values of coefficients at different dent depth

	Coefficient	
D (mm)	a	b
(0,15)	4.045	-0.08
(15,25)	16.66	-0.105
(25,35)	24.813	-0.099
(35,55)	38.444	-0.097
(55,115)	30.366	-0.073

When the other parameters remain unchanged, the relationship between the maximum displacement of lateral dent and pipe wall thickness can be expressed by the index function model below:

$$DMX = ae^{bt} \quad (5)$$

And the relationship between the maximum displacement of axial dent and pipe wall thickness can be expressed by the power function model below:

$$DMX = at^{b} \quad (6)$$

The Table 5 and 6, respectively list out the coefficients of Eq. 5 and 6 between the maximum displacement and pipe wall thickness under the different dent depth.

The corresponding correlation coefficient square of the expression in Table 3 and 4 are more than 0.95, indicating a satisfactory fitting effect. The classification is according to the principle of fitting the best. In addition, the coefficients can also be determined by the interpolation method when pipe diameter fall out of those listed in Table because the values of d/D and the maximum displacement are linearly correlated.

Pipe diameter: Figure 16 and 17, respectively show the relationships between the two kinds of dent maximum displacement (DMX) and pipe diameter (D) in case of different ratio of longitudinal dent length and pipe

Table 6: Values of coefficients at different dent depth

	Coefficient	
D (mm)	a	b
(0,20)	662.82	-2.25
(20,30)	3991.14	-2.55
(30,40)	9800.80	-2.66
(40,50)	16521.50	-2.69
(50,60)	27777.53	-2.75
(60,70)	39236.49	-2.77
(70,80)	48345.85	-2.77
(80,90)	54163.99	-2.75
(90,100)	50745.87	-2.64

Table 7: Values of coefficients at different L/D

	Coefficient	
L/D	a	b
(0,0.1)	0.0717	0.003
(0.1,0.2)	0.1210	0.003
(0.3,0.4)	0.1959	0.003
(0.4,0.5)	0.2329	0.003
(0.5,0.6)	0.2655	0.003
(0.6,0.7)	0.2903	0.003

Table 8: Values of coefficients at different L/D

	Coefficient	
L/D	a	b
(0,0.1)	2.91 E (-8)	2.65
(0.1,0.2)	2.65 E (-8)	2.74
(0.3,0.4)	5.49 E (-8)	2.68
(0.4,0.5)	1.53 E (-8)	2.56
(0.5,0.6)	3.76 E (-8)	2.45
(0.6,0.7)	7.31 E (-7)	2.36

diameter (L/D) when the other parameters is unchanged. The values of L/D are, respectively 0.1, 0.2, 0.7, 0.4, 0.5, 0.6, 0.7 from down to up in two figures.

As can be seen from the above two figures, change curves are very similar and closed to linear correlation. As a whole, the maximum displacement is elevated with increasing the values of pipe diameter. It is worth noting, for lateral typical dent, the displacement change is fluctuated at bigger pipe diameter with the bigger values of L/D. But, these fluctuations may be the result of calculation error.

When the other parameters remain unchanged, the relationship between the maximum displacement of lateral dent and pipe diameter can be expressed by the index function model below:

$$DMX = ae^{bD} \tag{7}$$

And the relationship between the maximum displacement of axial dent and longitudinal dent length can be expressed by the power function model below:

$$DMX = aD^{b} \tag{8}$$

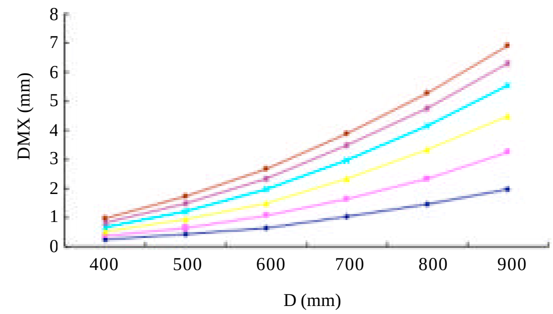

Fig.17: Relationship of the maximum lateral typical dent displacement and pipe diameter

The Table 7 and 8, respectively list out the coefficients of the Eq. 7 and 8 between the maximum displacement and pipe diameter under the different L/D.

The corresponding correlation coefficient square (R^2) of the expression in Table 7 and 8 are more than 0.95, indicating a satisfactory fitting effect. The classification is according to the principle of fitting the best.

MULTI FACTOR ANALYSIS OF DISPLACEMENT

Lateral typical dent: When d/D and D/t are changed while maintaining the other parameters constant, the relationship between the maximum displacement, d/D and D/t can be expressed as:

$$DMX = 0.008\left(\frac{d}{D}\right)^{0.618}\left(\frac{D}{t}\right)^{2.133} \tag{9}$$

The correlation coefficient square of the fitting formulae is 0.94.

When L and D are altered while maintaining the other parameters unchanged, the relationship between the maximum displacement, L and D can be expressed as:

$$DMX = 4.726D^{1.703}L^{0.704} \tag{10}$$

The correlation coefficient square of the fitting formulae are more than 0.99.When the pipe inner pressure is equal to other values, due to the relationship of stress and pipeline pressure is linear correlation, it can be got by interpolation method. In other more internal pressure fluctuations cases, more research was needed to determine the each factor of the multi-factor expressions.

Axial typical dent: When d/D and D/t are changed while maintaining the other parameters constant, the relationship between the maximum displacement, d/D and D/t can be expressed as:

$$DMX = 0.0124\left(\frac{D}{t}\right)^{2.657}\left(\frac{d}{D}\right)^{1.34} \quad (11)$$

The correlation coefficient square of the fitting formulae is 0.94.

When L and D are altered while maintaining the other parameters unchanged, the relationship between the maximum displacement, L and D can be expressed as:

$$DMX = 6.28D^{2.114}L^{0.284} \quad (12)$$

The correlation coefficient square of the fitting formulae are more than 0.99.When the pipe inner pressure is equal to other values, due to the relationship of stress and pipeline pressure is linear correlation, it can be got by interpolation method. In other more internal pressure fluctuations cases, more research was needed to determine the each factor of the multi-factor expressions.

RESULTS

Displacement variation characteristics:

- For the relationship between dent depth and displacement, the variation of lateral typical dent is more complicated than axial. The change curve of lateral typical dent is more close to the parabolic curve and the axial one is more close to the straight line. This shows that the influence of dent type on the relationship between the displacement and dent depth is quite big. As a whole, the maximum displacement is elevated with increasing dent depth. But when the values of D/t are more than 35, the maximum displacement of lateral dent increased first and then decreased with increasing dent depth. So, for lateral dent, the more D/t is big namely the more pipe tend to thin, the more change trend of maximum displacement with the dent depth variation is obvious. This is a very special characteristic
- For the relationship between longitudinal dent length and displacement, the maximum displacement is elevated approximately with increasing the values of L/D and the relationship between the maximum displacement and L/D is closed to linear. In addition, the former changes less significantly with varied L/D at lower pipe diameter values and vice versa
- For the relationship between pipe wall thickness and displacement, the change curves are all smooth curve and the maximum displacement is elevated with increasing the values of D/t. For axial typical dent, displacement variation is quite uniform with increasing D/t at different values of d/D. But, for lateral typical dent, displacement variation is reduced with increasing D/t at different values of d/D
- For the relationship between pipe diameter and displacement, the change curves of two kinds of dent are very similar and closed to linear correlation. As a whole, the maximum displacement is elevated with increasing the values of pipe diameter. But, for lateral typical dent, the displacement change is fluctuated at bigger pipe diameter with the bigger values of L/D

Mathematical models:

- When the other parameters remain unchanged, the relationship between the maximum displacement of lateral dent and dent depth can be expressed by the sine function (Sine brackets for radian) $DMX = a \sin(bd+c)$ and the relationship between the maximum displacement of axial dent and dent depth can be expressed by the power function $DMX = ad^b$.
- When the other parameters remain unchanged, the relationship between the maximum displacement of lateral dent and longitudinal dent length can be expressed by the found function $DMX = aL^b$ and the relationship between the maximum displacement of axial dent and longitudinal dent length can be expressed by the sine function $DMX = a \sin(bL+c)$
- When the other parameters remain unchanged, the relationship between the maximum displacement of lateral dent and pipe diameter can be expressed by the index function $DMX = ae^{bt}$ and the relationship between the maximum displacement of axial dent and longitudinal dent length can be expressed by the power function $DMX = aD^b$
- When the other parameters remain unchanged, the relationship between the maximum displacement of lateral dent and pipe diameter can be expressed by the index function $DMX = ae^{bD}$ and the relationship between the maximum displacement of axial dent and longitudinal dent length can be expressed by the power function $DMX = aD^b$

ACKNOWLEDGMENTS

This study is partially supported by the Grants from the National Natural Science Foundation of China (No. 50974105), the Research Project of Ministry of Housing and Urban-Rural Development (No. 2013-R3 -12) and the Applied Basic Research Project of Sichuan Province (No. 2013JY0098 and No. 2011JY0138).

REFERENCES

Al-Muslim, H.M. and A.F.M. Arif, 2011. Effect of geometry, material and pressure variability on strain and stress fields in dented pipelines under static and cyclic pressure loading using probabilistic analysis. Pressure Vessel Technol., 133: 1-13.

Allouti, M., C. Schmitt, G. Pluvinage, J. Gilgert and S. Hariri, 2012. Study of the influence of dent depth on the critical pressure of pipeline. Eng. Fail. Anal., 21: 40-51.

Beak, J.H., Y.P. Kim, W.S. Kim, J.M. Koo and C.S. Seok, 2012. Load bearing capacity of API X65 pipe with dent defect under internal pressure and in-plane bending. Mater. Sci. Eng A, 540: 70-82.

Hojjati, M.H. and S.A. Lukasiewicz, 2008. Filtering algorithm for radial displacement measurements of a dented pipe. Int. J. Pressure Vessels Piping, 85: 344-349.

Limam, A., L.H. Lee and S. Kyriakides, 2012. On the collapse of dented tubes under combined bending and internal pressure. Int. J. Mech. Sci., 65: 1-12.

Noronha Jr., D.B., R.R. Martin, B.P. Jacob and E. de Souza, 2010. Procedures for the strain based assessment of pipeline dents. Int. J. Pressure Vessels Piping, 87: 254-265.

Rinehart, A.J. and P.B. Keating, 2002. Length effects on fatigue behavior of longitudinal pipeline dents. Proceedings of the 4th International Pipeline Conference, September 29-October 3, 2002, Alberta, Canada, pp: 1849-1858.

Wu, Y., C. Xuebo and Z. Peng, 2011. FE calculation and strength analysis of the II type dent on pipeline. J. Pet. Mach., 39: 41-44.

Wu, Y., Z. Peng and X. Yanping, 2013. The stress analyses of the plain dent on pipeline based on FEM. Trans. China Welding Inst., 34: 57-60.

Wu., Y., Z. Li, Y. Yan and R.Z. Wang, 2013. FE calculation and analysis of the I type dent size influence on peak cycle stress. Energy Educ. Sci. Technol. A Energy Sci. Res., 31: 1053-1058.