Crack Detection of Pipe Using Static Deflection Measurement Method

Jatin M. Patel[#1], Prof. Mitesh J. Mungla[#2]

[#1, #2] *Mechanical department(Cad/Cam), Gandhinagar Institute of Technology, Gandhinagar Gujarat, India*

Abstract

A method of detection of crack location based on measurement of deflection of long pipes under bending loads is presented in this work. Crack is considered to be cross-sectional with straight front parallel to its diameter and perpendicular to the plane of deflection. The crack is modeled by a rotational spring whose stiffness can be determined using the linear elastic fracture mechanics approach. The identification of a single crack in a beam based on the damage-induced variations in the static deflection of that beam. Pipes supported like cantilever beams have been examined. The details of the method are presented. Experiments have been carried out using steel, aluminum and U-PVC pipes to demonstrate the effectiveness of the method. Cracks were introduced by wire-cut machining.

Keyword: Crack Detection in pipe, Static Deflection Measurement, Rotational spring model, TPSDM

1. INTRODUCTION

In several areas of civil and mechanical engineering, at present, real challenges arising for the control, maintenance and retrofitting of existing structures and machinery concern the diagnostic identification of damages. Pipe, one of the five leading transportation tools, plays an important role in petrochemical industry ,power plants, chemical plants, gas and oil transportation, etc.. Crack present in the component may grow during service and may result in the component failure once they grow beyond a critical limit. It is desirable to investigate the damage occurred in the structure at the early stage to protect the structure from possible catastrophic failures. Developing pipe testing technique can avoid or decrease accidents and is an important guarantee for the safety service of pipe. Many reasons, such as corrosion damage, fatigue, creep damage and erosion, lead to pipe damage. However, fracture is always the final failure form. Therefore, crack diagnosis of the pipe is the most significant problem in non-destructive testing.

There are various Non-destructive techniques (NDTs) available for the detection of the crack in the structural and mechanical components. To this purpose, nondestructive testing is of great interest under several respects, because it can provide a direct assessment of integrity of structures during service or can be employed to assess the residual resistance of a structure after the occurrence of a strong seismic event. At present, multiple techniques, for instance, leakage magnet detection technology, ultrasonic detection technology, eddy detection technology and acoustic emission detection technique, have been widely used in identifying the crack. Nevertheless, these traditional non destructive testing technologies are of low efficiency, and require complex instruments. At the same time, they need to detect the tested objects point by point. They are efficient but time consuming, expensive and laborious, particularly for slender beam like components. Therefore, researcher proposed a new detection technique based on vibration, based on natural frequency, based on deflection measurement etc, which can improve detection efficiency so as to determine crack location and size. It also can be utilized in detecting pipe damage in service.

2. CRACK DETECTION METHODS

Basically Two types of methods are available for detection of crack in mechanical components. one is conventional method and second is non conventional method,

1. Conventional (Non-Destructive Testing - NDT) methods
   - I. Leakage magnet detection technology
   - II. Ultrasonic detection technology
   - III. Eddy detection technology
   - IV. Ultrasound acoustics based assessment techniques etc.
2. Non conventional Methods
   - I. Natural frequency method
   - II. Wavelet analysis
   - III. Modal (Vibration) Analysis
   - IV. Finite element method of second generation wavelets
   - V. Static Deflection Measurement Method

Low detection efficiency, require complex instruments, time consuming, laborious and expensive. Due to this listed limitations, there is scope of alternative of conventional method for crack detection. Therefore, people proposed a new detection technique based on vibration, which can improve detection efficiency so as to determine crack location and size. It can be also utilized in detecting pipe damage in service.

The objective of this work is to detect crack in pipe conveying fluid also to identification of crack location and crack size with conveying fluid in pipe and supporting objectives are to develop efficient and reliable strategy for crack detection in pipe which is pressurized by conveying fluid.

S.S.Naik [1] has demonstrated static deflection measurement method for detection of crack in pipe concluded maximum errors in prediction of crack location is about 9% for both Al & M.S pipe and Rotational spring stiffness for steel it is higher than Al. and it is decreases with increases crack depth. Kaushar H. Barad et al. [2] have been investigated detection of the crack presence on the surface of beam-type structural element using natural frequency. S.M. Murigendrappa et al. [3] have been investigated Experimental and theoretical study on crack detection in pipes filled with fluid. E.Douka et al. [4] have been investigated Crack identification in beam using wavelet analysis, The fundamental vibration mode of a cracked cantilever beam is analyzed using continuous wavelet transform and both the location and size of the crack are estimated. Junjie Ye et al. [5] have been investigated on Pipe crack identification based on finite element method of second generation wavelet, a new method is presented to identify crack location and size, which is based on stress intensity factor suitable for pipe structure. Salvatore Caddemi et al. [6] have been investigated on the identification of a single crack in a beam based on the knowledge of the damage-induced variations in the static deflection of the beam.

In case of static deflection measurement method for crack detection is experimentally validate easily compare to other methods also Deflection is easy to measure by dial gauges compare to natural frequency & wavelet methods and not require complex instruments like FFT analyzer, accelerometers etc.

Rizos et al. [7] have represented the crack as rotational spring in modal analysis for a cantilever beam having a rectangular cross section as shown in Figure 1.

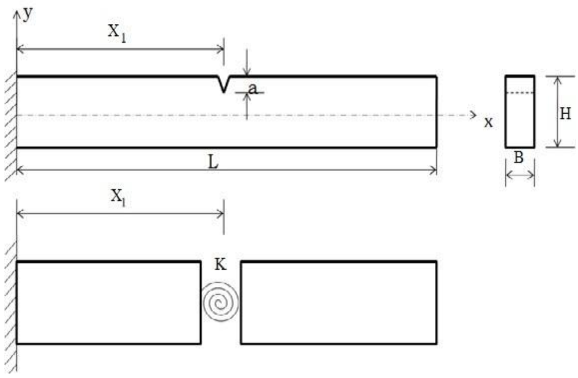

Figure 1. Crack Model by rotational spring

The modelling for the detection of crack in slender pipes is based on the assumption that crack introduces only local discontinuity in the slope at the crack location and a very small difference exists between the mode shapes of the pipes with and without a crack. [8] Therefore, a pipe containing a crack, for example in $\theta = 0^0$ orientation, can be conveniently represented by two pipe segments connected by a rotational spring of stiffness K_t at the crack position shown in Figure 2.

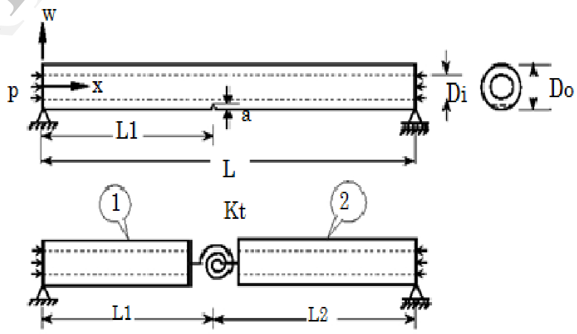

Figure.2 Crack in vertical orientation and its representation by rotational spring

When the rotational spring is used to represent a crack, the spring acts as sink for the energy released due to the crack. This energy is equal to the difference in energies of pipes with and without crack. The spring stiffness *Kt* can be determined experimentally using deflection method or vibration method. For a cantilever beam with load acting at the free end,

$$K_t = \frac{M^2_{emptypipe}}{P(\delta_c - \delta_{nc})}$$

where P is load acting at the free end, $M_{empty\ pipe}$ is the bending moment due to *P* at the crack section at a distance L_2 from the support and, δ_c and δ_{nc} are the deflections along the load line for pipes with and without crack respectively. This relation provides the basis for determination of variation of K_t with crack size by the deflection method. Thus, if K_t is known, crack size *a/t* can be obtained using these plots.[8]

3. MATHEMATICAL FORMULATION

The equation of deflection for a crack-free beam is given by [1]

$$EI\frac{d^2y_{nc}}{dx^2} = -M \qquad (1)$$

Since M = -W(L - x), using the boundary conditions y_{nc} = 0 at x = 0 and dy_{nc}/dx = 0 at x = 0, the following relations for slope and deflection respectively are obtained

$$\frac{dy_{nc}}{dx} = -\frac{W}{6EI}\left(\frac{x_c^{\ 2}}{2} - Lx_c\right) \qquad (2)$$

$$y_{nc} = \frac{Wx^3}{6EI} - \frac{WLx^2}{2EI} \qquad (3)$$

For modeling a beam with a crack, it is split into two segments (Fig.3.1). Deflection of segment I can be found out by following the procedure adopted for crack-free beam earlier.
That is,

$$EI\frac{d^2y_{Icr}}{dx^2} = -M = -W(L-x) \qquad (4)$$

Using the boundary conditions as y = 0 and dy/dx = 0 at x = 0, slope and deflection of the beam at $x = x_c$ are given by

$$\frac{dy_{Icr}}{dx} = -\frac{Wx_c}{2EI}(2L - x_c) \qquad (5)$$

$$y_{Icr} = -\frac{Px_c^2}{6EI}(3L - x_c) \qquad (6)$$

Similarly for the segment II (Figure 3) the slope and deflection are obtained solving the following governing equation

$$EI\frac{d^2y_{IIcr}}{dx^2} = -M = -W(L-x) \qquad (7)$$

There is a jump in slope at $x = x_c$. That is

$$\frac{dy_{IIcr}}{dx} = \frac{dy_{Icr}}{dx} + \frac{M}{K} \qquad (8)$$

Further, the displacements are continuous

$$y_{IIcr} = y_{Icr} \qquad (9)$$

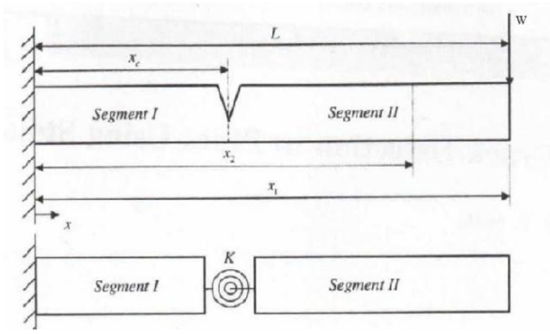

Figure.3 Cantilever beam with crack and its representation using rotational spring

This gives

$$y_{IIcr} = -\frac{WLx^2}{2EI} + \frac{Wx^3}{6EI} - \frac{M}{K}(x - x_c) \quad x_c \le x \le L \qquad (10)$$

Extra deflection δy due to the presence of crack for any point in the segment II, is given by

$$\delta y = y_{IIcr} - y_{nc} \qquad x_c \le x \le L \qquad (11)$$

It is noteworthy that δy = 0 for all locations over the segment I. using equation (3) and (10)

$$\delta y = \frac{M}{K}(x - x_c) \qquad x_c \le x \le L \qquad (12)$$

To solve for K and x_c for an unknown crack, it is necessary to measure δy at two locations say x_1 and x_2 within the segment II. If δy_1 and δy_2 are the measured data, then from equation (12)

$$\frac{\delta y_1}{\delta y_2} = r = \frac{(x_1 - x_c)}{(x_2 - x_c)} \qquad (13)$$

Alternatively,

$$x_c = \frac{x_1 - rx_2}{1 - r} \qquad (14)$$

K can then be determined using equation (12)

$$K = \frac{-P(L - x_c)(x_1 - x_c)}{\delta y_1} = \frac{-P(L - x_c)(x_2 - x_c)}{\delta y_2} \qquad (15)$$

Equations (14) and (15) give the crack location and rotational spring stiffness respectively [1]

The use of TPSDM can be also extended to study of crack extension problems. For such a study, measurements of static deflections corresponding to two instances in time, say t_1 and t_2, will be essential. Let the crack lengths be a_1 and a_2 and the crack growth be Δa (= a2 - a1), corresponding to the time interval. Using the static deflection measurements, rotational spring stiffness, say K_1 and K_2, corresponding to crack lengths a_1 and a_2, can be estimated. Finally, using variation of K with a/t obtained through the forward problem, a_1 and a_2 (and Δa in turn) can be estimated. Verification of this aspect can be the subject matter of an interesting study [1].

Determination of Rotational Spring Stiffness by Deflection Method

The rotational spring stiffness, K corresponding to a crack in a component can be found experimentally by the deflection method. The equation for rotational spring stiffness K is

$$K = \frac{M^2}{P(\delta c - \delta_{nc})} \qquad (16)$$

where M is bending moment at crack section and, δ_c and δ_{nc} are the deflections along the load line for cracked and crack-free beam respectively. Equation (16) gives the basis to obtain a variation of K with crack size (a/t) (Figure 4)

4. EXPERIMENTAL WORK

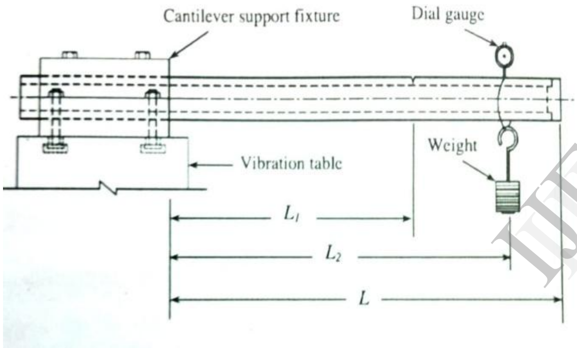

Figure.4 Experimental arrangement for measurement of static deflection of cantilever beam

Slender aluminium and mild steel pipes of uniform diameter were considered for experiments. Geometric and material properties of these pipes are given in Table 1. In all, 26 specimens made of both aluminium and mild steel were used. These include one crack-free specimen of each material. For static deflection measurements, the specimens were tested in cantilever configuration with a span of 0.95 m, using a clamping fixture made specifically for this purpose.

Figure 4 shows the experimental setup for measurement of static deflection to facilitate determination of K.

Table 1. Geometric and material data of MS and Al

Parameter	L(m)	D_0(m)	D_i(m)	δ(Kg/m^3)	E(GPa)
Steel	0.95	0.0378	0.0278	7.860	173.81
Al	0.95	0.04	0.0298	2.645	60.347

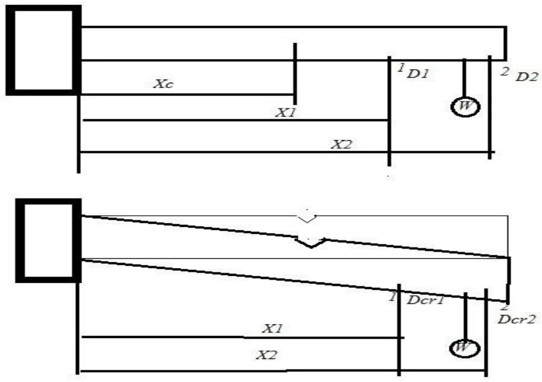

Figure.5 Measurement of Static Deflection At two locations with and without crack

5. RESULT AND DISCUSSION

The prediction of crack location by TPSDM is in good agreement with the actual location for both aluminium and steel pipes for crack size in the range of 20–80 % of the thickness when the crack is in 12 o'clock position. The prediction of the rotational spring stiffness is also possible using the proposed method. The rotational spring stiffness reduces as crack size increases.[1]

Table 2. Analysis of cantilever beam (ANSYS Software)

Inputs	
L (Length of Beam)	1000mm
H (Height of beam)	10mm
B (Width of beam)	40mm
E (Young modulus)	2.0e11
Poison ratio	
Load	100kg at 0.9 m distance from fix end
Crack Width(b)	1 mm
Crack Depth(a)	5mm
Crack depth ratio (a/t)	5
X_1 (measurement location 1 from fix end)	400mm
X_2 (measurement location 2 from fix end	800mm
Outputs	
D_1 (Deflection at X_1 location)	9.69027mm
D_2 (Deflection at X_2 location)	31.4235mm
Dcr_1 (Deflection after crack at X_1 location)	10.2509mm
Dcr_1 (Deflection after crack at X_1 location)	91.855mm
x_c is crack location of beam	395.6630mm

Table 3.Analysis of cantilever pipe (ANSYS Software)

Inputs	
Material of pipe	Mild steel
Length of pipe	0.95m
Outer diameter of pipe	0.0378m
Inner diameter of pipe	0.0278m
Density of pipe material	7.860kg/m^3
Modulus of elasticity for pipe material	173.81GPa
Force applied in Y-Direction	80N
Outputs	
Deflection of uncracked pipe	967.6 µm
Deflection of cracked pipe	987.19 µm

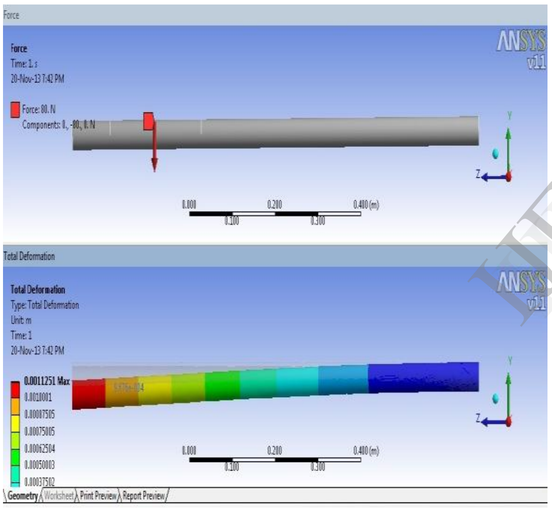

Figure.6 Deformation without Uncracked Cantilever Pipe

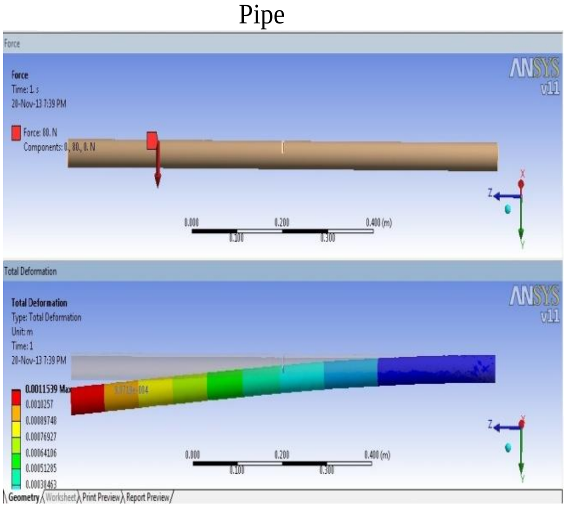

Figure.7 Deformation with Cracked Cantilever Pipe

Table 4. Result

Sr. No	Method	Deflection for uncracked pipe in µm	Deflection for cracked pipe in µm	Error in %
1	Deflection method	878	885.333	0.82%
2	ANSYS Software	967.6	987.19	1.98%

Analysis of cantilever beam in ANSYS software for finding the deflection of two different locations in beam with and without crack. Based on this analysis, relative errors were calculated in crack location is 20.78%.

Comparison of two different methods for calculating the deflection in cantilever pipe is shown in above table 4. In Deflection Method [1] difference between the values of deflection of pipe with crack and without crack is 7.333 µm while same data of pipe can be analyzed in Software, difference between the values of deflection of pipe with crack and without crack is 19.59 µm. Based on that above data find the relative errors in deflection method and Ansys Software are 0.82% and 1.98 % respectively. This deflection method is validate compare with Ansys software because of the relative error is small between two method.

6.CONCLUSION

From the above results it can be concluded that:

Deflection method is validate with experimentally and ANSYS Software with relative error is 0.82% and 1.98% corresponding.

REFERENCES

[1] S.S.Naik, "Crack detection in pipe using static deflection measurement", J.Inst.Eng.India Ser,93(3)(2012) 209-215

[2] Kaushar H. Barad , D.S.Sharma, Vishal Vyas, "Crack detection in cantilever beam by frequency method" .NUiCONE, Procedia engineering 51(2013) 770-775

[3] S.M. Murigendrappa, S.K. Maiti , H.R. Srirangarajan, "Experimental and theoretical study on crack detection in pipes filled with fluid", Journal of Sound and Vibration 270 (2004) 1013–1032

[4] E.Douka , S. Loutridis , A. Trochidis, "Crack identification in beam using wavelet analysis", International Journal of solid s and structures 40(2003) 3557-3569

[5] Junjie Ye, Yumin He, Xuefeng Chen, Zhi zhai, Youming wang, Zhengija He, "Pipe crack identification based on finite element method of second generation wavelet", Mechanical system and signal processing 24(2010) 379-393

[6] Salvatore Caddemi, Antonino Morassi, "Crack detection in elastic beams by static measurements", International Journal of Solids and Structures 44 (2007) 5301–5315

[7] Rizos, P, Aspragathos, N., Dimarogonas, "Identification of crack location and magnitude in a cantilever beam from the vibration modes". Journal of Sound and Vibration 138, 381–388

[8] Sachin S. Naik and Surjya K. Maiti, "Special issues related to detection of circumferential crack at different orientation in pipe by vibration method", ICSV14(2007)