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Vibration Analysis of Cracked Beam Subjected to a Moving Load by Finite Element Method

[1*]Polat Kurt, [1]Oguzhan Mulkoglu and [1]Sadettin Orhan
[1]Faculty of Engineering, Department of Mechanical Engineering Ankara Yildirim Beyazit University, Turkey

Abstract

This article is about the finite element analyzes of simply supported, single cracked beam under moving load with different conditions. FE analysis is performed by the help of Ansys Apdl program. A code for solving the problem is written and it is verified by the existing articles which was handled the same problem by numerical method. After the code is verified, a beam with different crack depth, crack location and moving load speed is analyzed to observe how the different conditions effect the vibration response of the beam. The deflection is higher in cracked beam and it is increasing by the crack depth increases. The moving speed of the load and crack location are also effect the time response of the beam. The finite element analyzes results are given in detail in the article.

Keywords: Vibration, time response, cracked beam, moving load, Ansys

1. Introduction

Structures under moving load have been a very important research topic in structural dynamics because of their application in railways and bridges. Nowadays, due to transportation has become heavier and faster, this field of research continues to receive considerable attention in the literature. There are many analytical methods on moving load and moving mass problems such as modal analysis methods [1–3], Green function method [4], Galerkin method [5], finite difference method [6] and discrete element analysis method [7].

Analytical methods may not be always suitable for moving load problems, for this reason numerical solutions are needed. Finite element method (FEM) is one of them and it is very common method that widely used for dynamic problems. There are many researchers used FEM in their various kind of vibration analysis such as beam structure subjected to moving distributed load [8], vibration of truss structure [9], free vibration of cracked beams [10] and crack detection in beams [11]. There are also alternative numerical formulations to solve vibration of a beam subjected to a moving force such as frequency-domain spectral element modeling [12].

Cracks are sign for detecting the structural damages in earlier stages. The presence of cracks in a structure affects the structure's vibration response since it induces local stiffness reduction. There are some researches that investigated the effects of different parameters of crack (e.g., length, location, depth) on vibration characteristics [1,13,14].

*Corresponding author: Address: Department of Mechanical Engineering, Yıldırım Beyazıt University, Ulus, Ankara 06050, TURKEY. E-mail address: pkurt@ybu.edu.tr Phone: +90(312) 324 15 55

Moving load effect on cracked beams was also studied analytically in Refs [1] and [14]. In this paper, vibration characteristics of cracked beams subjected to a moving load are obtained using FEM. Moving load parameters (speed and mass level) and crack parameters (location and depth) are investigated and compared in each other graphically in detail.

2. Modelling

Cracked beam under moving load is modelled and analyzed in Ansys Mechanical Apdl (Ansys Parameter Design Language) program. It is based on code writing often in batch mode. Workbench is more visual and has graphical user interface where you can analyze with click operations without using codes. It is easier to use especially in 3D analyses and has updated geometries. On the other hand, if you know what is going on in the background while analyzing, it is more useful to use Apdl. Once you derive code of analysis, it is very easy to make changes on analysis and run for different parameters.

Analysis in Ansys is performed in 3 steps which are preprocessor, solution and postprocessor. Preprocessor is preparation procedures of the problem for solution. The material properties, modelling of the problem, meshing, boundary conditions are all defined in this process. After the problem definition, analysis type and loads are defined and the analysis is performed in solution. To get the results and investigate the data obtained from analysis, postprocessor is used.

In postprocessor, a 2-D beam was modelled as an area. Transverse crack was presented in underside of the beam as shown in Figure 1.

Plane182 was selected as element type. This element type is used for 2-D modelling of solid structures. It is represented by 4 nodes with 2 degrees of freedom which are translation in x and y directions. Z direction is restricted. It allows us to describe the 3-D beam in 2 dimensions by thickness option in real constants [15].

The beam material was selected as steel and mechanical properties (elasticity, density and poison's ratio) of steel were defined.

The area was meshed to the nodes by a constant element size $0.1\ m$ with quadratic shape. Because the nodes were used for defining moving load they must had equal distance to each other. After meshing the beam, the boundary conditions for simply supported beam were defined for two ends of the beam. All ends of the beam were restricted for the motions in y direction but left side is restricted also in x direction and they were free to rotate.

The moving load was applied to top face of the beam. It was applied and removed instantly one by one for all nodes from left top corner to right top corner by 'do' command in the analysis code. The time differences between the forces applied on two consecutive nodes identify the velocity of the load.

In solution step, transient analysis with full option was selected to perform this analysis which is used to analyze the time responses of the designs for time dependent loads.

The commands for the analysis is given in the Appendix.

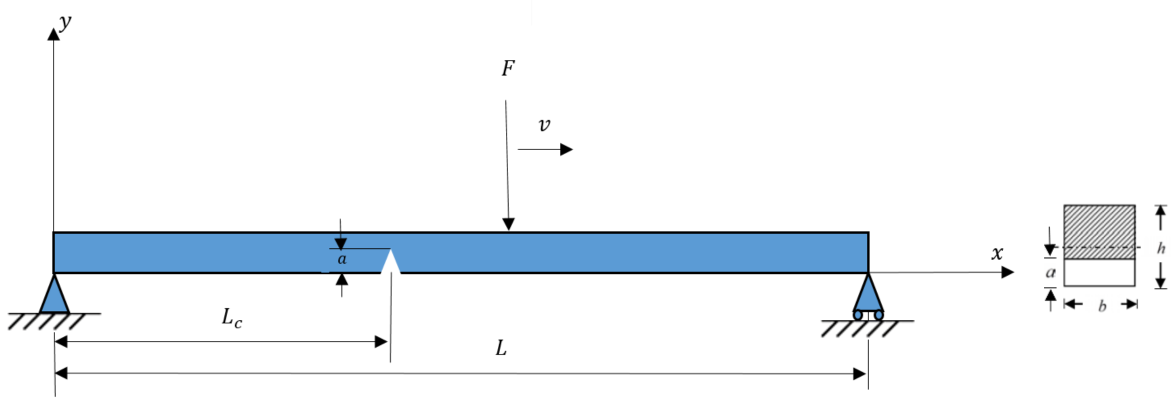


Figure 1. Representation of the problem

3. Results and Discussion

First of all, to check the reliability of analysis code, same study is run and compared with the study from literature for response of a cracked beam under moving load [1]. In this study, a simply supported steel beam with $50x1x0.5\,m$. dimensions is considered for different conditions as moving load, speed and crack depth. Same beam in same conditions are performed in Ansys Apdl and results are compared with analytical results from the article. Results showed that the FEM model is very capable of capturing the results as seen in figure 2.

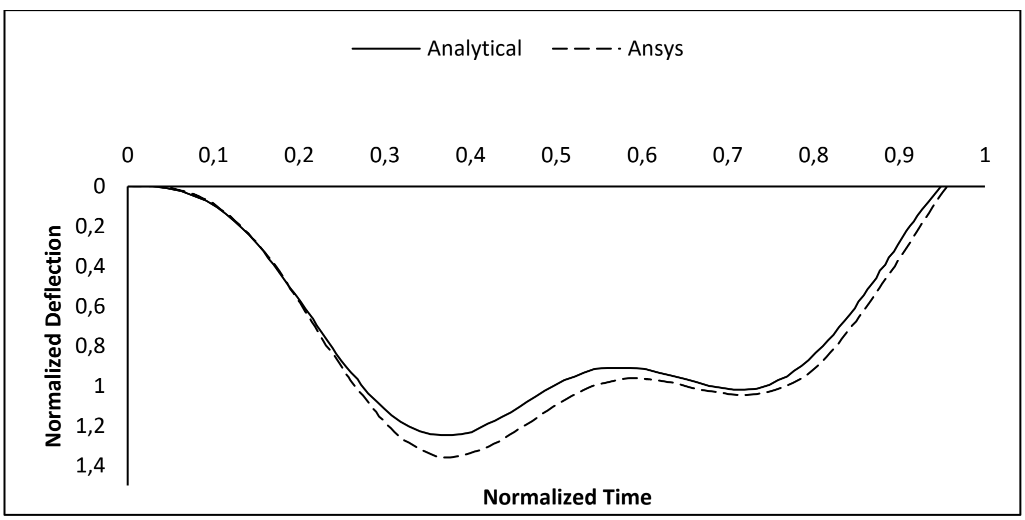
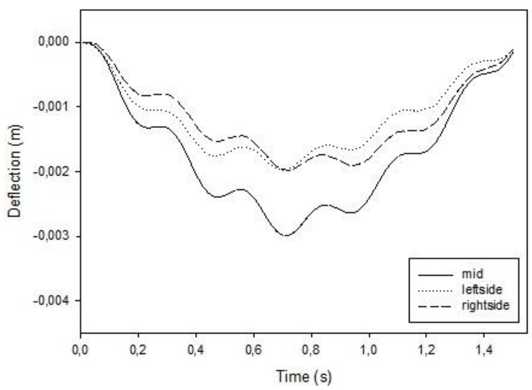


Figure 2. Time response comparison of Ansys analysis with analytical results

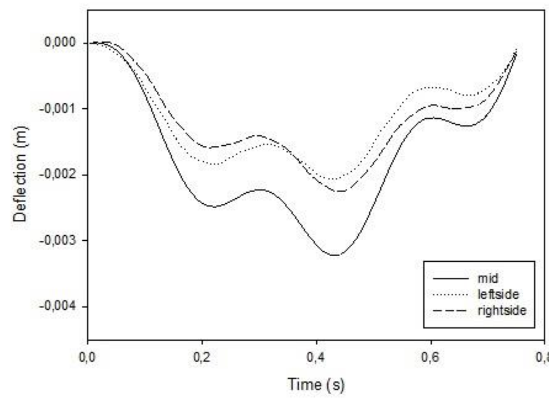
After verifying Apdl code, simply supported beam subjected to moving load is analyzed with different conditions to see the effect of conditions on vibration response. A beam with length 15

m. and 0.4 m. square profile. The material of beam is steel with modulus of elasticity as $2100\ GPa$, density $7860\ kg/m^3$ and poisson ratio 0.3. A transverse crack is also presented under the beam to see the crack effect on time response of the beam. The results are taken from 3 points (midpoint (mid), $L_m/L = 0.25$ (leftside) and $L_m/L = 0.75$ (rightside) where L_m is the distance of measurement point from left side of the beam) of the beam and given in figures. Analyses are performed for different crack depths, crack locations and velocities.

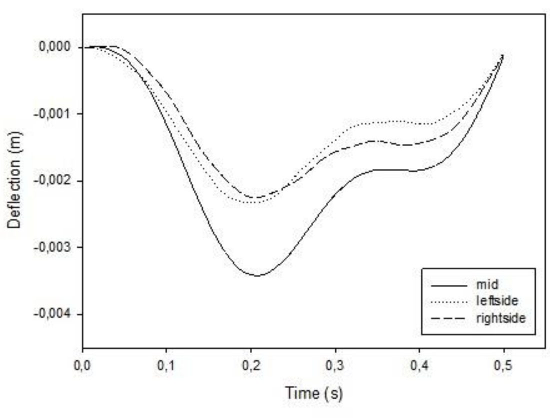
Figure 3 shows how the velocity of the moving load effects the time response of beam. The other conditions are fixed like as crack depth ($a/h = 0.5$), crack location (midpoint) and load ($f_0 = 15000\ N$). The maximum deflection is increasing with increasing speed of moving load. Time also represents moving load location on the beam. Moving load position at where the maximum deflection occur also changes with velocity.



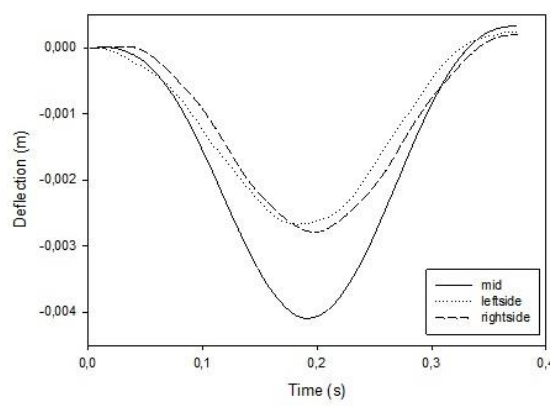
(a)



(b)



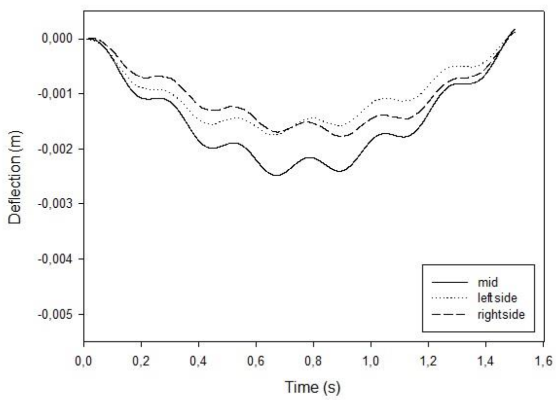
(c)



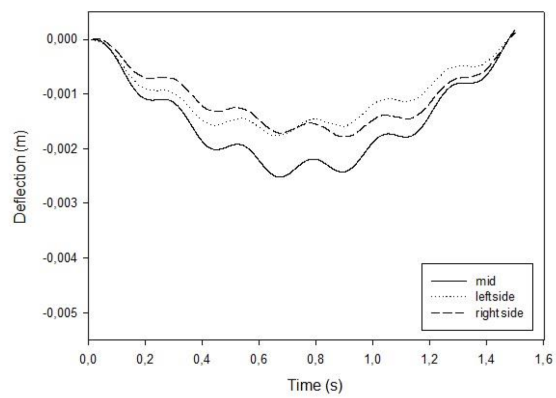
(d)

Figure 3. Time response of the beam with different velocities, (a) $v = 10\ m/s$, (b) $v = 20\ m/s$, (c) $v = 30\ m/s$, (d) $v = 40\ m/s$

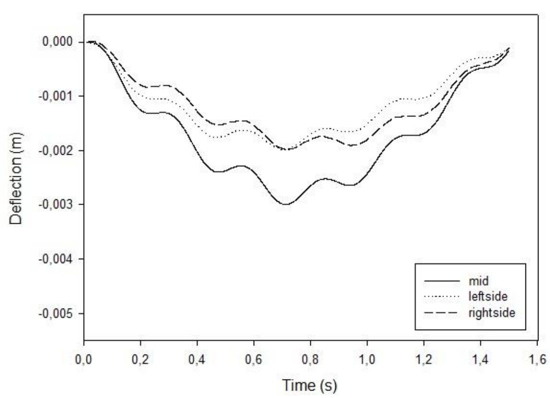
Figure 4 shows the effect of crack depth at midpoint of the beam. Moving load ($f_0 = 15000\ N$) and moving speed ($v = 10\ m/s$) are fixed to see how crack depth effects time response. Velocity is selected as 10 m/s because the response of the beam can be seen more effective in lower speeds. The ratio of the crack depth to the height is a good indication to see the effect of crack depth to time response of the beam. As seen in the figures, there is no such difference between $a/h = 0$ and $a/h = 0.2$. It can be said that small cracks don't effect of time response but bigger cracks where crack depth ratio is bigger than 0.5 significantly increase deflection of the beam.



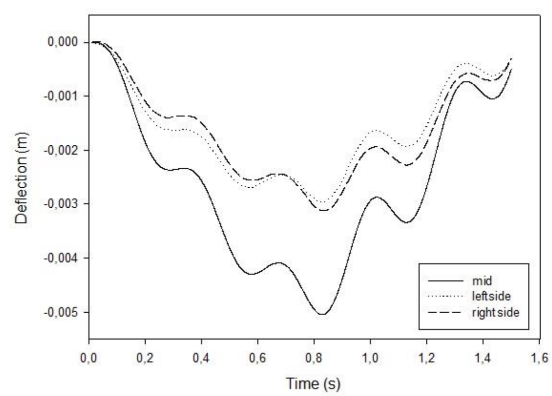
(a)



(b)



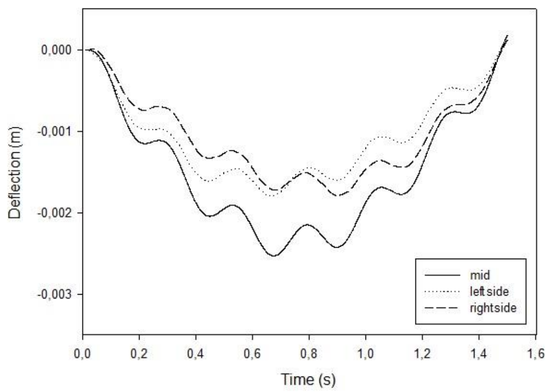
(c)



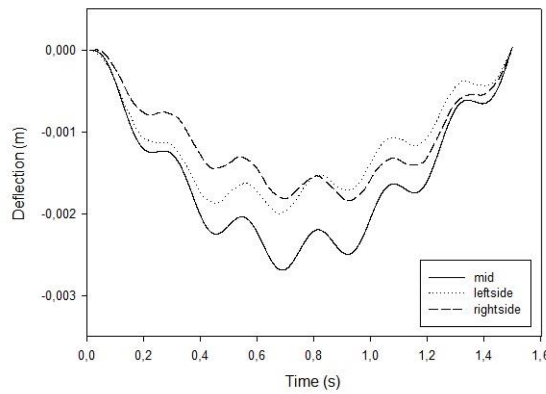
(d)

Figure 4. Time response of the beam with different crack depths, (a) $a/h = 0$, (b) $a/h = 0.2$, (c) $a/h = 0.5$, (d) a/h=0.75

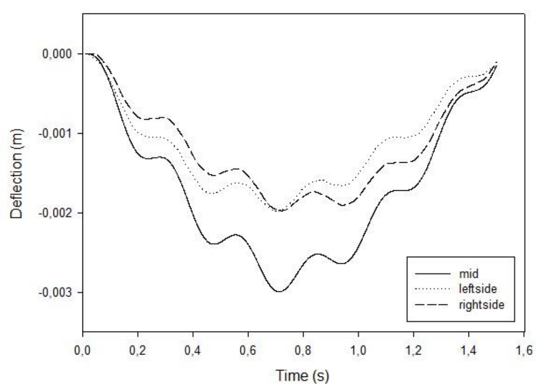
Change of the time response according to the ratio of crack location from left side (L_c) to the length of the beam under moving load for fixed velocity ($v = 10\ m/s$) and fixed crack depth ratio ($a/h = 0.5$) can be seen for four different values of L_c/L in Figure 5. The maximum deflection occurs for 3 different measurement points where crack location is at midpoint of the beam. Nevertheless, for measurements from left side and right side positions, the maximum deflection could also occur when the crack location is in their own side. It can be said that the time response of deflection is affected by crack location and also by measurement point.



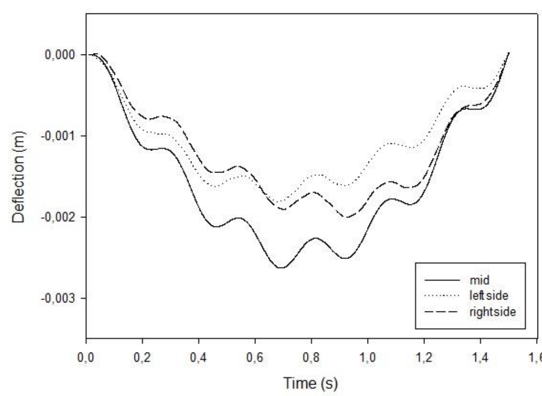
(a)



(b)



(c)



(d)

Figure 5. Time response of the beam with different crack locations, (a) $L_c/L = 0.1$, (b) $L_c/L = 0.25$, (c) $L_c/L = 0.5$, (d) $L_c/L = 0.75$

Conclusion

The effect of different conditions like as crack depth, crack location and moving load velocity on simply supported beam were investigated. Ansys Apdl program is used to obtained the results. Apdl code is obtained for one time and it's verified with the article [1]. The different conditions are performed. It is observed that crack depth, crack location and velocity effect the deflection response of the beam. Increasing velocity increases the deflection and also effects the response shape of the beam. In high speeds, the response shape is more smooth than in low speeds. Crack affect on the time response is seen more significantly in high crack depths.

The different results can be obtained for different conditions and different materials to see the effects on the displacement in further studies.

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Appendix

Ansys Apdl code for vibration analysis of beam under moving load with a crack at midpoint. ($v = 20\ m/s, a/h = 0.5$)

```
/prep7

!element type

et,1,plane182,,,3

l=15

h=0.4

b=0.4

a=0.2

r,1,b

mp,ex,1,2.06e11

mp,dens,1,7860

mp,nuxy,1,0.3

k,1,0,0

k,2,0,h

k,3,l,h

k,4,l,0

k,5,l/2+0.05,0

k,6,l/2,a

k,7,l/2-0.05,0

l,1,2

l,2,3

l,3,4

l,4,5
```

```
l,5,6
l,6,7
l,7,1
al,1,2,3,4,5,6,7
esize,0.1
amesh,all
d,1,ux,0
d,1,uy,0
d,156,uy,0
/solu
elboyut= 0.1
l1=15
f0=-15000
v=20
tson=l1/v
/solu
antype,4
outres,all,all
kbc,0
dtnod=elboyut/v
k=1
*do,xcor,0,l1,elboyut
nsel,all
nsel,s,loc,x,xcor-elboyut
```

```
nsel,r,loc,y,h

nsel,r,loc,z,0

f,all,fy,0

nsel,all

nsel,s,loc,x,xcor

nsel,r,loc,y,h

nsel,r,loc,z,0

f,all,fy,f0

time,(k-1)*dtnod

nsel,all

solve

k=k+1

*enddo

Finish
```