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Contribution to the Study of the Effect of Cracks on the Behavior of Concrete and Steel Structures

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Abstract: The appearance of cracks in structures is a very important issue, moreover, it is a complex problem on the numerical level. These cracks should never be taken lightly. They can be the sign of serious disorders especially if they are structural cracks. The objective of this article is to study the effect of the crack existence in civil engineering structures: concrete and metallic structure in terms of frequencies and eigenmodes using the extended finite element method X-FEM and to compare the results obtained with the classical finite element method (Structure without crack).

Keywords: Cracks, X-FEM, FEM, Steel, Concrete.

INTRODUCTION

Structural design is essentially about ensuring an acceptable level of safety that reduces the risk of failure. In order to carry out the calculation of these structures, it is necessary to know the response of this material to the various demands. Indeed, the structures are full of defects due to pores, voids and shrinkage cracks, which can cause macro-cracks propagation when the structure is in use [1].

To describe the phenomenon of cracking in a material, it is necessary to define the crack itself which is a sudden discontinuity occurring in this material under the effect of internal or external stresses, where the material is separated on a certain surface.

As long as the forces of stress, it causes a great concentration of stress at its bottom. Its propagation, under the effect of sufficient constraints, combined or not with an aggressive environment leads to rupture.

The analysis of structural failure is an important issue in the field of civil engineering [2]. Concrete and steel are the most used materials for building structures. And to represent the state of cracking of these structures, the conventional methods of calculation are not enough we will have to use more consistent numerical methods, in particular the method of the X-FEM extended finite elements [3].

Belytschko and Black [4] and Moës *et al.*, [5] introduced this method to model cracks and their propagation by finite elements with a minimum of remeshing. Based on a classical finite element, it adds enrichment functions to take into account the discontinuity of the displacement field along the crack and its asymptotic shape at the crack tip. Its main objective is to predict the evolution of a crack until the complete rupture of the structure [6].

The objective of this work is therefore to see the effect of cracking in concrete and steel structures by evaluating the frequencies and the eigen modes and to compare the results obtained by using the X-FEM with those obtained by the classical FEM and in this case without the existence of a crack.

Modeling of crack

According to Belytschko and Moës and [4, 5], the field of displacement of the X-FEM method is written as follows:

$$\boldsymbol{u}^h(\mathbf{x}) = \sum_{I\in N} N_I(\mathbf{x}) \left[\boldsymbol{u}_I + \underbrace{H(\mathbf{x})\boldsymbol{a}_I}_{I\in N_\Gamma} + \underbrace{\sum_{\alpha=1}^{4} F_\alpha(\mathbf{x})\boldsymbol{b}_I^\beta}_{I\in N_\Lambda} \right] \quad (1)$$

where $\boldsymbol{u}_I$ are the finite element conventional nodal displacement degrees of freedom/unknowns, $\boldsymbol{a}_I$, the additional degrees of freedom to model the discontinuity associated to the crack tip, and $\boldsymbol{b}_I$, the additional degrees of freedom to model the singularity of crack tip, associated with the elastic asymptotic given hereafter. N is the set of mesh nodes, N_Γ is the set of nodes contained in elements crossed by the crack; N_Λ is the set of nodes associated to elements containing the crack tip.

To represent the lips of the crack, degrees of freedom representing the jump of displacement are added [5]. These degrees of freedom are obtained by using the Heaviside H function introduced in the following way:

$$H(x) = \begin{cases} +1 & \text{If x is above } \Gamma \\ -1 & \text{If x is below } \Gamma \end{cases} \quad (2)$$

Where Γ represents the geometry of the crack and x the position vector of a point of Ω.

On the same principle, the singular field in the vicinity of the tip can be approached using a base of enrichment functions representing the asymptotic fields of a crack:

$$\left[F_\alpha(x), \alpha = 1-4\right] = \left\{\sqrt{r}\sin\left(\frac{\theta}{2}\right), \sqrt{r}\cos\left(\frac{\theta}{2}\right), \sqrt{r}\sin\left(\frac{\theta}{2}\right)\sin(\theta), \sqrt{r}\cos\left(\frac{\theta}{2}\right)\cos(\theta)\right\} \quad (3)$$

Where (r, θ) are the coordinates in the local coordinate system related to the front of the crack.

Example of a case study

A civil engineering structure has been the subject of a parametric study of the proposed modeling.

It consists firstly of a concrete structure of width $2W = 1$ m, height $2H= 4$ m and thickness $e_p = 0.1$ m, and in the second a steel structure element with the same dimensions these structures are studied without and with crack (see Fig. 1).

Two cases of the crack location are considered; edge crack and central crack. The structure is excited by the acceleration loading registered at the Boumerdes earthquake in 2003 –Algeria.

The material properties are given by:

For concrete structure: Modulus of elasticity $E = 3.10^{10}$ Pa, poisson's ratio $v = 0.18$.

For steel structure: Modulus of elasticity $E = 21.10^{10}$ Pa, poisson's ratio $v = 0.30$.

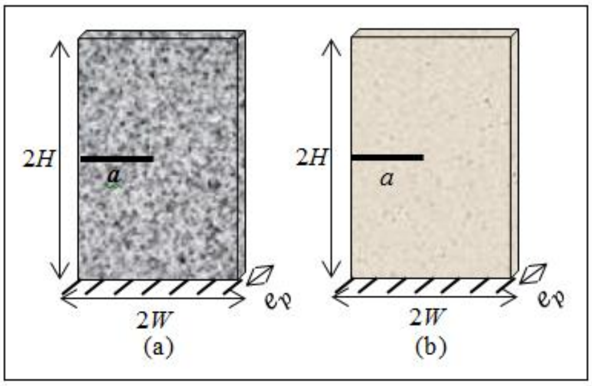


Fig-1: Cracked structure: (a) Concrete structure, (b) Steel structure.

A parametric study of the crack effect on the vibration behavior of the structure is conducted. A calculation of eigenfrequencies and eigen modes of structure with and without the crack is performed to see his influence.

RESULTS AND DISCUSSIONS

Eigenfrequencies

The following tables summarize the first natural frequencies (8 modes) found with concrete and steel structures**:**

Table-1: Eigenfrequencies of the concrete structure obtained without and with crack.

Mode	***a/W***				
	0	**0.25**	**0.5**	**0.75**	**0.95**
1	3.398	3.215	2.667	1.618	0.430
2	27.849	26.831	22.846	16.602	11.813
3	49.473	48.412	46.770	45.903	43.695
4	54.636	54.672	54.658	54.640	54.619
5	80.496	80.518	80.487	80.476	80.461
6	101.051	101.002	101.000	100.996	100.994
7	114.458	114.626	114.624	114.622	114.621
8	120.472	120.359	120.339	120.330	120.321

Table-2: Eigenfrequencies of the steel structure obtained without and with crack.

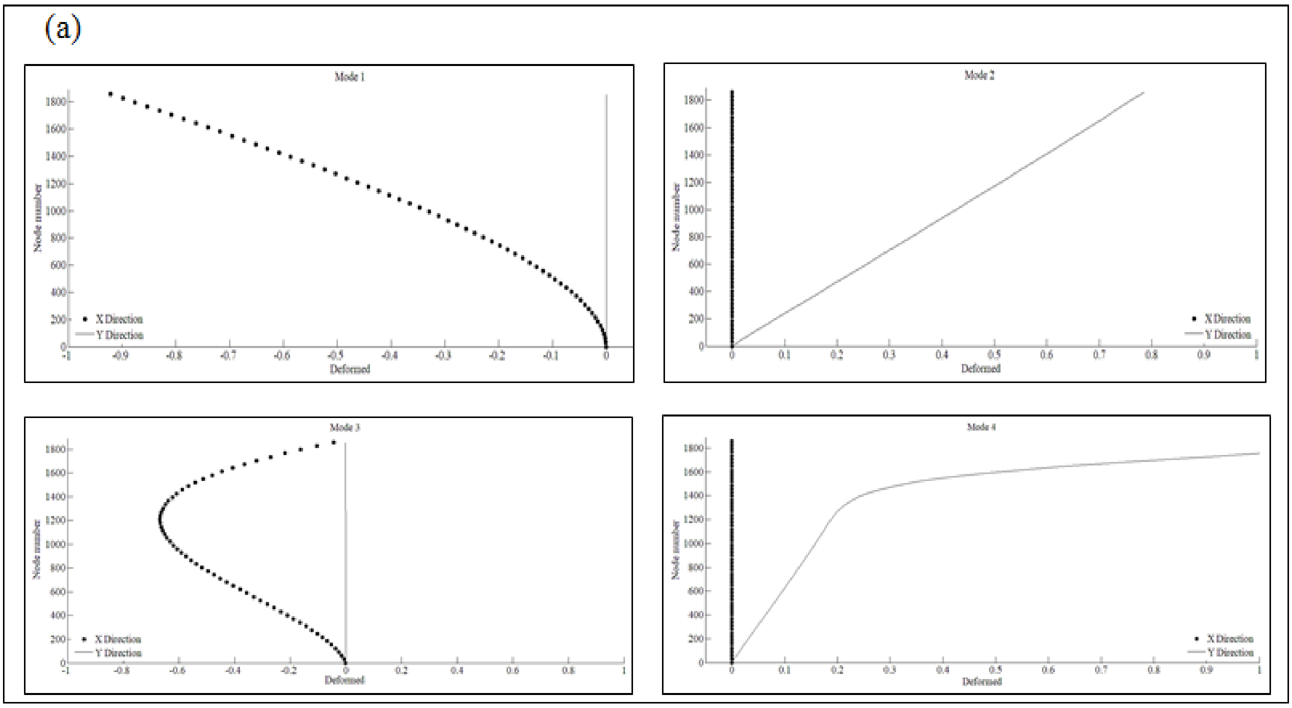
Mode	***a/W***				
	0	**0.25**	**0.5**	**0.75**	**0.95**
1	9.172	8.680	7.210	4.378	1.145
2	75.037	72.202	60.846	43.800	31.241
3	122.247	118.313	113.109	111.054	104.791
4	150.754	150.822	150.716	150.580	150.452
5	224.219	224.047	223.541	223.373	223.188
6	285.303	275.374	263.571	260.004	256.148
7	282.733	282.647	282.646	282.627	282.553
8	298.817	299.114	299.109	299.098	299.075

From the results of Table-1 and 2 we can notice as much as the crack length increases, the eigenfrequencies decrease especially in the four first modes. Thus, we can conclude that the eigenfrequencies decrease with the crack existence which reduces the rigidity of the structure.

In addition, we can say that a steel structure is more rigid than concrete, which is very clear in the Table-1 & 2.

Eigen modes

To see the effect of the crack on mode shapes in both directions X and Y, we take the case of relative crack length a/W = 0.5, i.e when we have a decrease in the rigidity of the structure. Comparing the mode shapes of the center line of the structure with the case of the structure without crack (Fig-2).



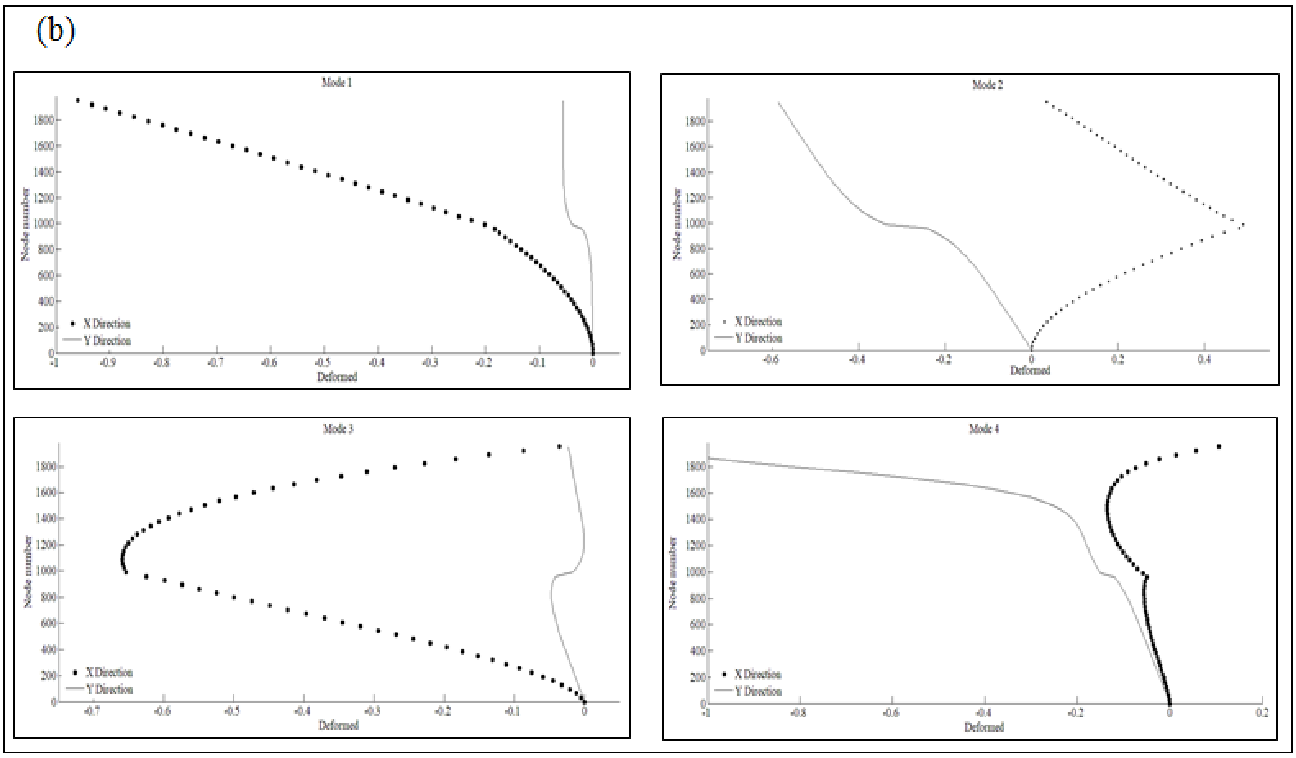


Fig-2a: The first four eigenmodes: (a) Uncracked Concrete structure, (b) Concrete Structure with crack *a/W* = 0.5, (c) Uncracked Steel structure, (d) Steel Structure with crack *a/W* = 0.5.

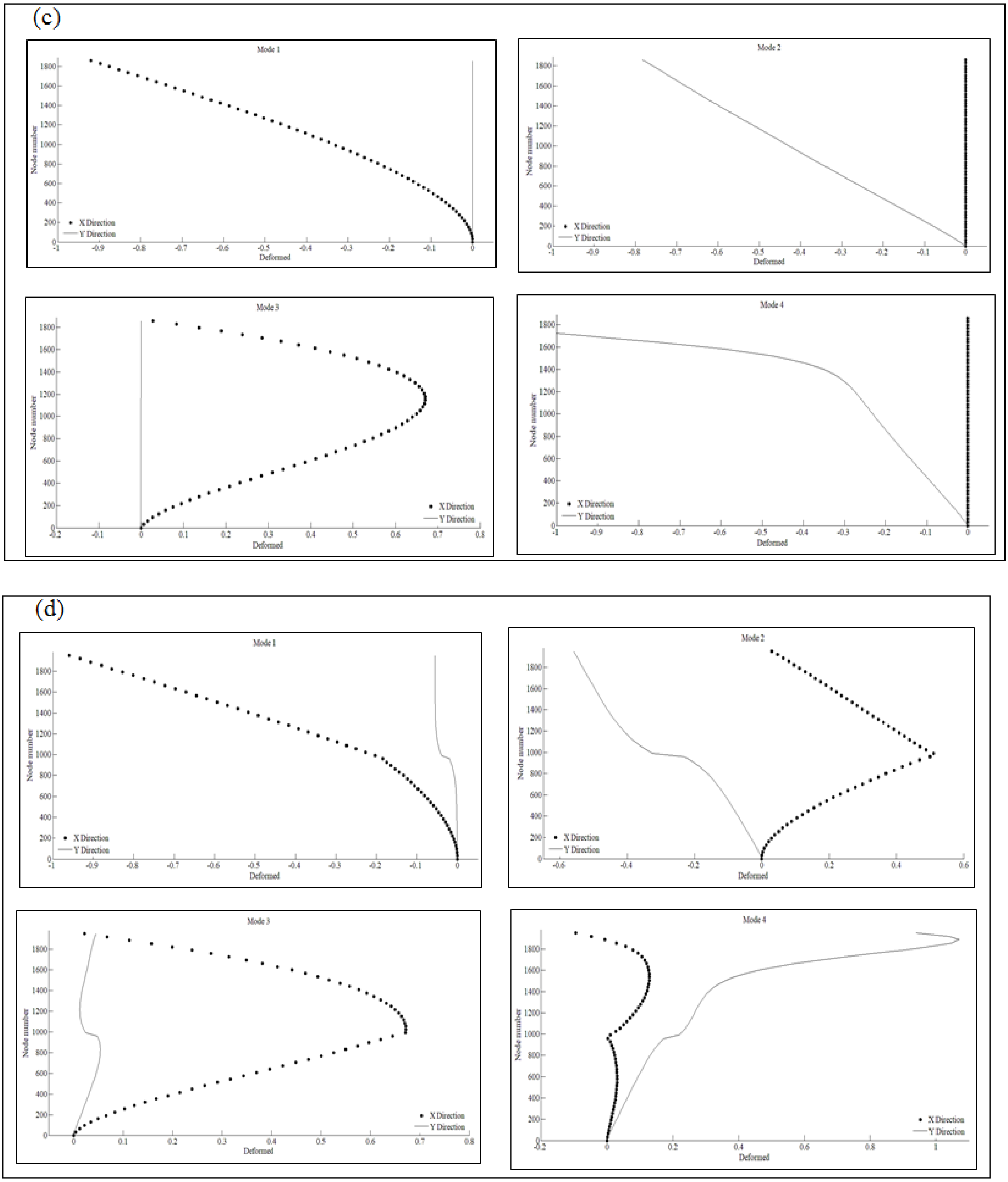


Fig-2b: The first four eigenmodes: (a) Uncracked Concrete structure, (b) Concrete Structure with crack *a/W* = 0.5, (c) Uncracked Steel structure, (d) Steel Structure with crack *a/W* = 0.5.

The shape of the Eigen modes (Fig-2) shows an independence of mode shapes in the two directions X and Y in the case without crack. But with the presence of the crack, we see an appearance of a coupling between the deformations in the X and Y directions on the Eigen modes, which lead to the structure to move in the two directions, overlooked an applied seismic excitation in a single direction. It is to add that the singularity point (crack tip) can be observed as a corner point in the X direction (which presents the Mode II, which is the sliding) and a point of discontinuity in the Y direction (which presents Mode I, which is the opening) (Fig. 2.b and 2.d) and these remarks are common to both cases of concrete and steel structures.

CONCLUSION

In this work, we have studied the modeling of cracked structures using the X-FEM focusing on the effect of the crack existence in the structure.

A parametric study was conducted on a practical problem of a cracked concrete and steel structure subjected to seismic excitation. A calculation of eigenfrequencies and eigen modes of structure with and without the crack is performed to see his influence.

In conclusion, we can summarize this work as follows:

- The eigenfrequencies decrease with the existence of a crack.
- Appearance of a coupling between the deformations according to X and Y directions is observed on the eigen modes of the structure with crack.
- The point of singularity (tip of crack) can be noticed on the paces of the eigen modes where it appeared as a point angular in the direction X and a point of discontinuity in the Y direction. Which leads to say that the deformation according to x direction presents the mode II of rupture which is the sliding and the deformation according to Y direction presents the mode I which is the opening.

REFERENCES

1. Legrain, G., Moës, N., & Huerta, A. (2008). Stability of incompressible formulations enriched with X-FEM. *Computer Methods in Applied Mechanics and Engineering*, *197*(21-24), 1835-1849.
2. Matallah, M., & La Borderie, C. (2007). Modélisation numérique de l’ouverture des fissures dans les structures en béton. *Rencontres Universitaires de Génie Civil, Bordeaux, France*.
3. Jan, Y. (2016). *Modélisation de la propagation de fissure sur des structures minces, soumises à des sollicitations intenses et rapides, par la méthode X-FEM* (Doctoral dissertation, Université de Lyon).
4. Belytschko, T., & Black, T. (1999). Elastic crack growth in finite elements with minimal remeshing. *International journal for numerical methods in engineering*, *45*(5), 601-620.
5. Moës, N., Dolbow, J., & Belytschko, T. (1999). A finite element method for crack growth without remeshing. *International journal for numerical methods in engineering*, *46*(1), 131-150.
6. Nehar, K. C., Hachi, B. K., Badaoui, M., Guesmi, M., & Benmessaoud, A. (2016). The evaluation of the spectral dynamic stress intensity factor by the x-fem method coupled with the spectral modal analysis.