Middle-East Journal of Scientific Research 15 (3): 439-445, 2013
ISSN 1990-9233

DOI: 10.5829/idosi.mejsr.2013.15.3.372

Genetic Programming in Optimum Shape of Brick Masonry Arches under Dynamic Loads

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Abstract: In this research genetic programming (GP) is used to evolve optimum shape of brick masonry arches under dynamic loads. Determination of dynamic loads in samples of semi-circular, obtuse angel, four-centered pointed, Tudor, ogee, equilateral, catenaries, lancet and four-centered arches is general goal of this research. They are analyzed and optimized under acceleration–time components of Elcentro earthquake. For arch response optimization, the results were used in Genetic Programming computational model. Then using provided rules for modeling, the mentioned arches are analyzed and optimized. Comparing the results of GP (Genetic Programming) method and FEM (Finite Element Method) method, shows that although precision is less in GP method, but the time of analysis and optimization is so much smaller in it.

Key words: Optimum Shape · Arch · Brick Masonry · Dynamic Load · Tensile Stress · Genetic Programming

INTRODUCTION

Masonry structures exist in the form of typical house and office buildings, but also include a wealth of invaluable structures which compose the fabric human history [1]. The need for masonry structure modeling and analysis tools is largely diffused worldwide. Very sophisticated models of extremely simplified methods are commonly used for seismic analysis of this kind of structures [2].

Brick masonry arches are known masonry structures which were built since the beginning of the earliest civilization. Evaluation of seismic response of structures is one of the popular subjects in recent years [3]. Nowadays, a high number of arches are constructed in seismic zones and despite their acceptable performance under dynamic loading, there is still overmuch need to improve their behaviors and to increase their safety during strong ground motion events. The research described in this paper is intended as a step in deriving such design strategies and deals with different samples arches under dynamic loads by genetic programming. Regarding to importance and application of arches in traditional structures, arches optimization has been considered [4].

There has been some research on brick masonry under dynamic loads [4]. Dynamic or time history analysis is an analytical method for determining reflections during earthquake in structures. Through this analysis, response of structure under loadings which are related to time has been studied [5]. Dynamic analysis and optimization of arches need to consume a longtime. In the field of structural optimization, one of the most popular evolutionary algorithms is genetic algorithm [6]. The present research goals are modeling, analyzing and optimizing complicated behaviors of semi-circular, obtuse angel, four- centered pointed, Tudor, ogee, equilateral, catenaries, lancet and four-centered arches, under dynamic load using genetic Programming.

The main importance of this research is showing the ability of analyzing and optimizing of every arch after one time of modeling in a so much shorter time.

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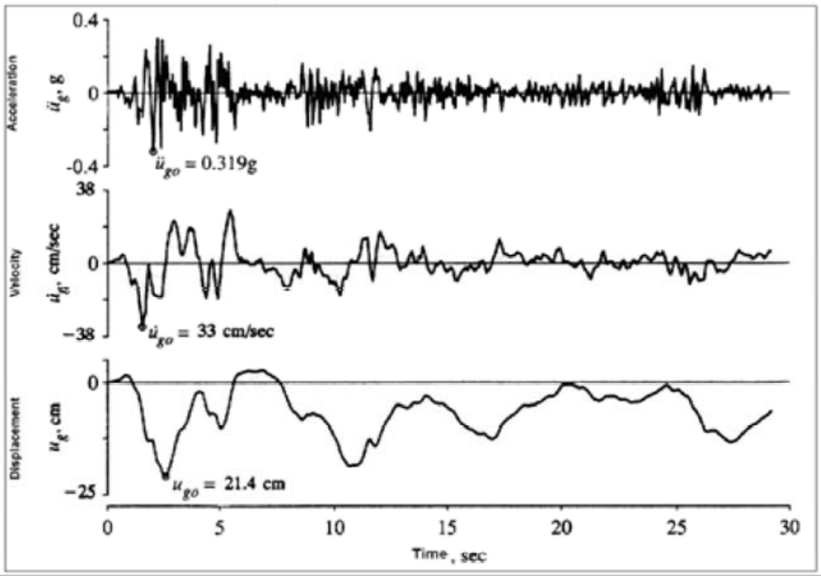


Fig. 1: North-south horizontal component of Elcentro earthquake

MATERIALS AND METHODS

Modeling, Analyzing and Optimizing Arch Shape Using FEM Software: Many earthquakes have occurred on the earth and in view of the fact that intensity and content of the frequency in each record of an earthquake varied with other records, it is so hard and impossible to reach an absolute conclusion from evaluating the vulnerability of concrete frames by using some analytical approaches [7]. At the first step arch modeling has been conducted by FEM software. Furthermore, dynamic analysis has been conducted applying north-south horizontal accelerations of Elcentro earthquake in which the time, maximum acceleration, maximum velocity and maximum displacement are 31.98 (s), 0.31 (g), 33 (cm/sec) and 21.4 (cm), respectively (Fig. 1) and SOLID65 is used for analysis in this stage. Arch shape optimization emphasized on the minimizing of arch weight. In FEM software, the base and top thickness, maximum tensile stress and weight of structure have been defined as design variable, state variable and objective function, respectively. Regarding the extra time for analysis and optimization, the optimization has been conducted in design optimum processor by means of Sub problem approximation method. This is an estimating method for variable designing, state and objective function via curve fitting tool. It is a general method for solving many engineering problems [8].

MATERIALS AND METHOD

Dimensions of a semicircular arch investigated in this study are shown in figure 2. According to shape optimization design variables, such as base thickness (t0) and top thickness (t1) as parameters, all the key points are defined as follows:

Point 1: (0, 0) Point (2): (R, 0) Point3: (-R, 0) Pint4: (0, R)
Point 5(R+t0, 0) Point6: (-R-t0, 0) Point 7: (0, R+t1)

In arch modeling, the tolerance increases because the thickness decreases from base to top [9]. It should mention that in modeled arch, the thickness decreases from base (t_0) to top (t_1) linearly and also arch thickness of axis is 20 (cm) in the length direction. The motion of

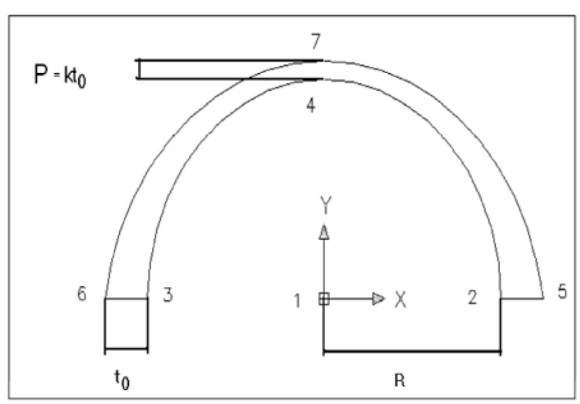


Fig. 2: Geometrical model of semicircular arch

Table1: Brick masonry characteristics [10]

density(ρ) (Kg/m^2)	Elastic modulus (N/m^2)	Allowable tension stress (f_t)	Poisson ratio (υ)
1460	5×10	0.5×10	0.17

Table 2: Effective coefficient in non elastic and nonlinear analysis [2]

motion coefficient for open crack	motion coefficient for close crack	allowable tension stress N/m^2	allowable compressive stress N/m^2
0.1	0.9	5	5

support nodes is zero and dynamic force has no effect on them. In addition, brick masonry is made by brick and mortar as homogenous material (Table 1). The efficient factors in the inelastic nonlinear analysis have been shown in table 2. In the present paper, arch radius limit (R), maximum tensile stress, base and top thickness in optimum state are considered as 4-8 (m), 49000-5100 (KN/m^3), 0.8- 1.44 (m) and 0.2-0.35 (m) respectively for all modeled arch.

Genetic Programming: Genetic programming (GP) is a process whereby a population of programs are initialized and evaluated against an objective. The programs that are most fit are selected and act as parent programs during crossover and mutation operations, which are then used to generate a new population. The new population is turn evaluated against the objective and the fitter individuals are selected for genetic operations once more [11].

RESULTS AND DISCUSSION

Arch Modeling Using GP Approach: We are going to exploit the GP approach of Ferreira [12, 13]. In this stage, regarding the definition of GP, the data for each arch will be analyzed to find the simulation models of each arch behavior. To achieve this aim, 1000 samples of each arch radius, base and top thickness and maximum tensile stress were chosen and analyzed by GP algorithm.

Genetic Programming Configuration: Related parameters for the training and testing of the GP model like Data, Program Structure, general setting, genetic operators and Numerical Constants are given in Table 3, 4, 5, 6 and 7, respectively.

We have exploited the GP approach of Ferreira [12] as described above using GP Algorithm and exploited the three features for modeling. The system calculates the feature weights using Genetic Programming. To do this we use GP finding function method. For training GP models we use 1000 samples of each arch was produced by FEM software and after one Million repetitions, some models were provided for each arch. Then for testing each arch

Table 3: GP data

Independent variables	3
Training samples	1000
Testing samples	50

Table 4: GP program structure

Literals	1000
Used variables	Radius, Base and Top Thickness

Table 5: GP general setting

Chromosomes	30
Genes	4
Head size	12
Tail size	33
Dc size	33
Gene size	87
Linking function	Addition

Table 6: GP genetic operators

Mutation rate	0 044
Inversion rate	0 1
IS transportation rate	0 1
RIS transportation rate	0 1
One-point recombination rate	0 3
Two- point recombination rate	0 3
Gene recombination rate	0 1
Gene transportation rate	0 1

Table 7: GP Numerical Constants

Constants per gene	2
Data type	Floating- point
Lower bound	-10
Upper bound	10
RNC mutation	0 01
Dc mutation	0 044
Dc inversion	0 1
Dc IS transportation	0 1

Table 8: Statistics-Training

Best fitness	100
Max fitness	100
Accuracy	100%

Table 9: Statistics-Training

Best fitness	83.45
Max fitness	100
Accuracy	86.50%

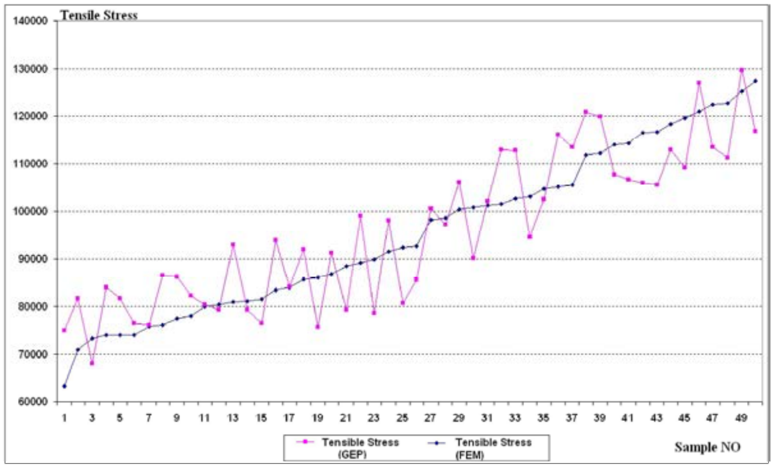


Fig. 3: Comparison between maximum tensile stress using FEM software and GP model in semicircular arch

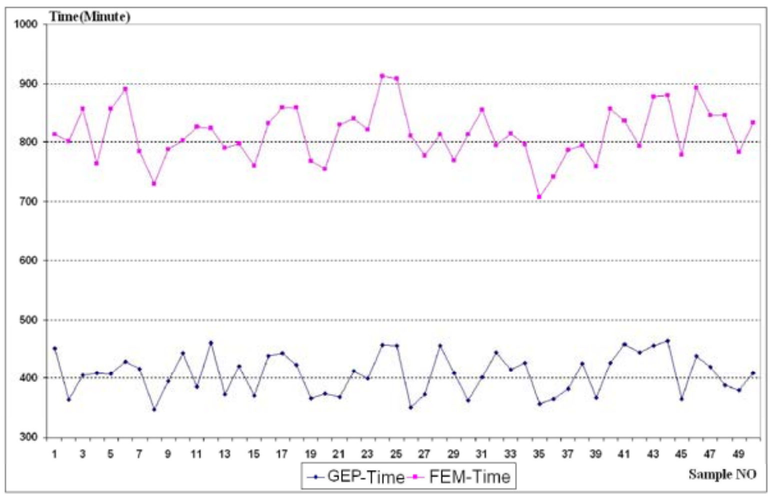


Fig. 4: Comparison between time of computing maximum tensile stress by FEM software and GP

model we produce Maximum tensile stress for 50 samples has been provided and error percent has been compared with another analyzed samples in FEM software.

Evaluation GP Model: We used 1000 Semicircular arch samples for training and 50 Semicircular arch samples for testing GP model and the results are given in table 8 and 9.

Maximum tensile stress was achieved for 50 samples of semicircular arches by GP. Figure 3 define comparison between maximum tensile stress in FEM and GP model. The mean of error percent in semicircular arch is 13.50%. Moreover, Figure 4 illustrates the diagram of comparison between time of maximum tensile stress computation using GP and FEM software, respectively.

Arch Optimization Using GP: In this stage, by means of GP model for each arch top and base thickness were optimized. Considering optimized maximum tensile stress which is 51000 (N/m^2), the range of radius, top thickness and maximum tensile stress in each arch are considered as input, so arch base thickness will be provided. In the next stage, size of arch radius, base thickness and maximum tensile strain are considered as input. So arch top thickness will be provided.

Top Thickness Optimization in Semicircular Arch Using GP: In this stage, 50 semicircular arch samples were chosen for top thickness optimization. Their optimum maximum tensile stress range, arch radius and base thickness were 49000 to 51000 (KN/m^3), 4~8 meter and 0.8 to 1.44, respectively. After ward, the top thickness was calculated and compared with top thickness in FEM software (Figure 6). Figure 5 show comparison of optimization time of top thickness optimization in semi circular arch.

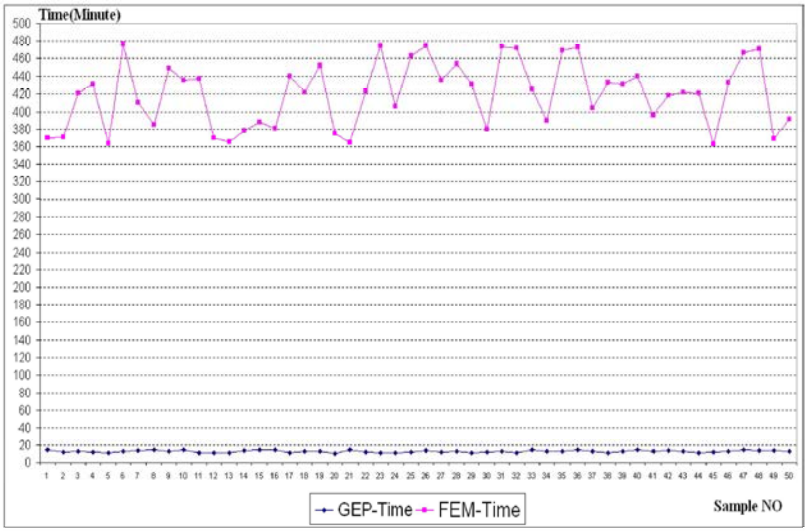


Fig. 5: Comparison between time of computing maximum tensile stress of semicircular arch using FEM software and GP model

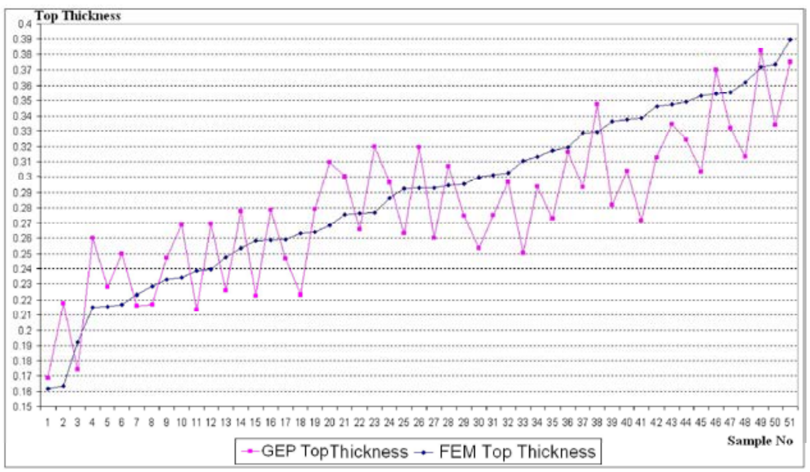


Fig. 6: Comparison of optimum range of arch top thickness using GP model and FEM software

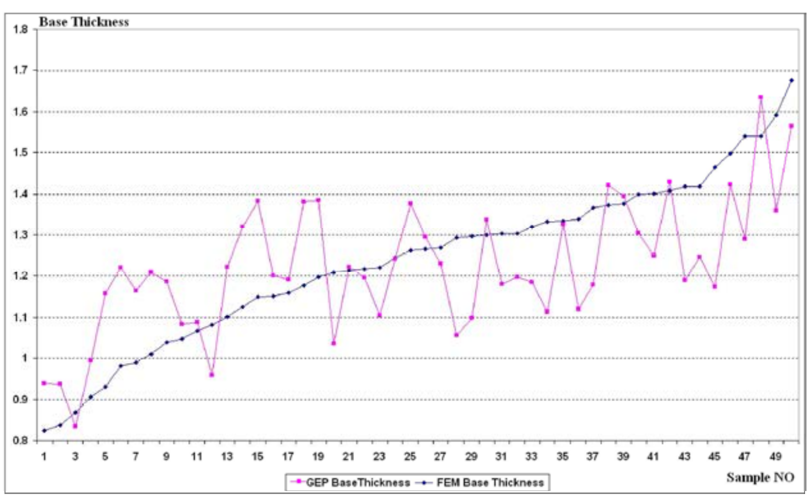
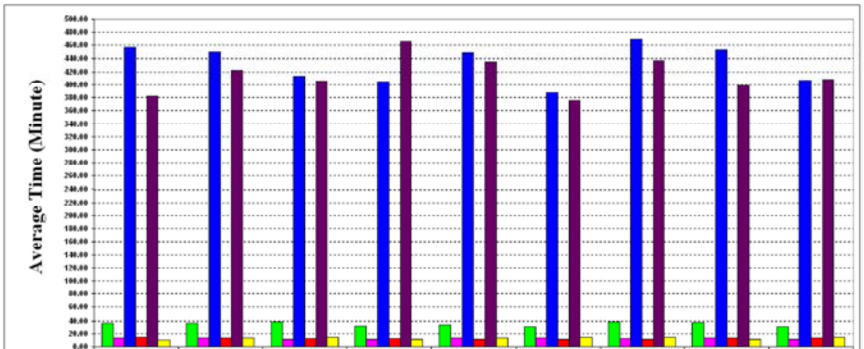
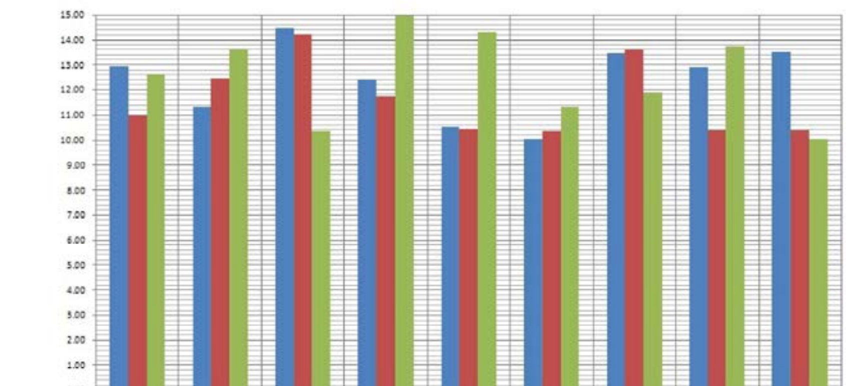


Fig. 7: Comparison of optimum range of arch base thickness using GP model and FEM software



	Catenary arch	Equilateral arch	Four centered pointed arch	four-centered arch	Lancet arch	Ogee arch	Optuse angle arch	Semicircular arch	Tudor arch
FEM Analyzing Average Time	36.51	36.09	38.29	31.63	33.53	30.93	38.58	37.72	30.50
GEPAnalyzing Average Time	13.70	13.14	11.48	11.03	13.43	13.33	12.13	13.11	11.37
FEM Top Thickness Optimizing Average Time	456.62	449.91	413.26	404.88	448.70	387.77	469.05	452.51	406.11
GEP Top Thickness Optimizing Average Time	14.70	12.85	12.04	11.60	10.62	10.87	10.86	13.35	13.32
FEM Base Thickness Optimizing Average Time	382.80	421.85	404.97	466.42	435.47	375.96	436.88	399.04	408.07
GEP Base Thickness	10.39	12.81	14.58	11.16	13.16	14.47	14.00	11.01	14.28

Fig. 8: Comparison between mean of analysis and optimization time of all discussed arches using FEM software and GP model



	Catenary arch	Equilateral arch	Four centered pointed arch	Four-centered arch	Lancet arch	Ogee arch	Optuse angle arch	Semi circular arch	Tudor arch
Base Thickness Error Percent AVG	12.96	11.33	14.50	12.41	10.52	10.05	13.46	12.92	13.53
Tensile Stress Error Percent AVG	10.98	12.45	14.23	11.76	10.43	10.37	13.62	10.38	10.42
Top Thickness Error Percent AVG	12.66	13.58	10.35	14.95	14.30	11.32	11.88	13.73	10.04

Fig. 9: Comparison between the mean of error percent of analysis of tensile stress and optimization of base and top thickness for discussed arches using GP model toward FEM software

Base Thickness Optimization in Semicircular Arch Using GP: In this section, 50 semicircular arch samples were chosen for top thickness optimization. Their optimum maximum tensile stress range, arch radius and base thickness were 49000 to 51000(KN/ m^3), 4~8 meter and 0.2 to 0.35, respectively. After calculation of base thickness-according to algorithm in figure 6, the results were compared with base thickness in FEM software (Figure 7). The mean of error percent of base thickness calculation was 11.93%.

CONCLUSION

In the present paper, nine arches- semi-circular, obtuse angel, four-centered pointed; Tudor, ogee, equilateral, catenaries, lancet and four-centered arches- were modeled using FEM software and GP model. Figures 8 and 9 show analysis and optimization time, the results which are provided by GP in arch modeling and the mean of error percent for arch analysis and its optimization, respectively.

Considering results, GP model can be used in simulation of all arches. Therefore, the time of calculation decreases. Also, it can be used in dynamic response, natural frequency and response of structure under different dynamic loads. To increase GP models precision, we can increase the number of Chromosomes which are larger than 30 and repeated more than 1000000 times are needed.

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