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Cellular Automata Approach in Optimum Shape of Concrete Arches under Dynamic Loads

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Abstract
Traditional methods in determination of optimum shape of structures don't scale well. This paper discusses the application of cellular automata (CA) to study of optimum shape in concrete arches under dynamic loads by cellular automata and presents a novel approach for that. In this paper, samples of semi-circular, obtuse angel, four- centered pointed, Tudor, ogee, equilateral, catenaries, lancet and four-centered arches are modeled. Then they are analyzed and optimized under acceleration–time components of Elcentro earthquake. Using cellular automata model and provided rules, the mentioned arches are analyzed and optimized. The results of error range and time of analysis in cellular automata model and FEM software compared. According the results, in CA method, precision is less but it has less time of analysis and optimization .

Keywords: optimum shape, arch, concrete, dynamic load, tensile stress, cellular automata.

1. Introduction

A growing interest in the preservation of heritage and historic structures has created a need for efficient method for analysis of arches that are the principal components of these structures. Arch is the oldest type of construction and have been around for thousands years.
They were originally build of stone or brick but now built of reinforced concrete or steel [2].
Arches are mostly known as structures as the load carrying system. In the last decades, various studies have been conducted by researchers on the response and evaluation of masonry and concrete arch under different actions [5]. Concrete arches have been used to span covering of

considerable length in many different applications. Structural efficiency is attributed to the curvature of the arch, which transfers vertical loads laterally along the arch to the abutments at each end [6].

There has been some research on brick masonry under dynamic loads [8]. Dynamic or time history analysis is an analytical method for determining reflections during the earthquake in structures, but the most important structural properties should be known prior to analysis of structure [4]. In the field of structural optimization, one of the modern method is CA. Dynamic analysis and optimization of arches need to consume a long time; it is necessary to use a proper computational model such as cellular automata to analyze and optimize the arches in less time and also for more acceptable results . Cellular automata is a decentralized computation model and one of the applications that require data processing is cellular automata in which a very large volume of data must be processed in a short time and the results of the processing must be reapplied to the automaton [11] . It is a good method for computation and simulation of complicated behaviors by local data [18].

At the present study, 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 cellular automata are conducted. Furthermore, the ability of analyzing and optimizing of every arch after one time of modeling in a so much shorter time is highlighted.

2. ARCH MODELING USING FEM SOFTWARE

By using FEM software, arch modeling has been conducted. 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. 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 [9].

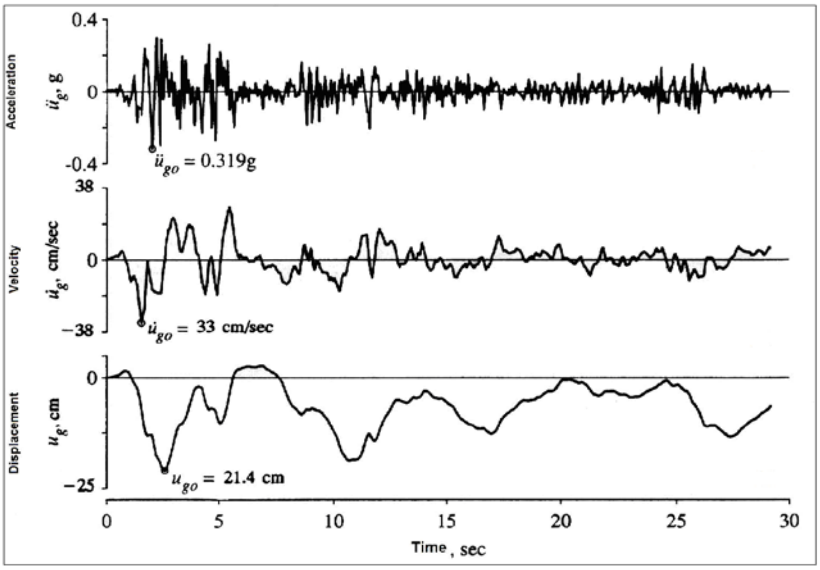


Fig.1. North-south horizontal component of Elcentro earthquake

2-1 Geometrical Modeling

According to shape optimization design variables, such as base thickness (t_0) and top thickness (t_1) as parameters, all the key points are defined as follows (fig.2):

Point 1: (0, 0) Point (2): (R, 0) Point3: (-R, 0) Pint4: (0, R)
Point 5(R+t0, 0) Point6: (-R-t_0, 0) Point 7: (0, R+t_1)

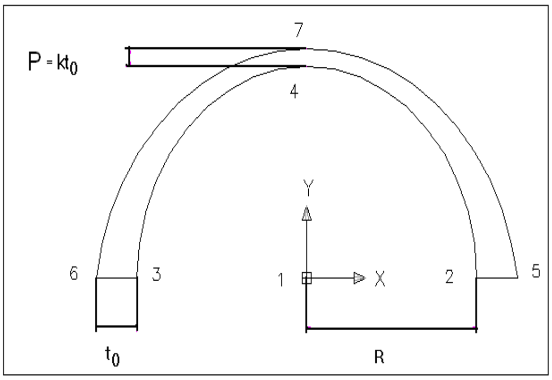


Fig.2. Geometrical model of semicircular arch

In arch modeling, the tolerance increases because the thickness decreases from base to top [6]. 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 support nodes is zero and dynamic force has no effect on them. Specifications of used concrete in arch modeling are shown at 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), 4000-4100 (KN/m^2), 0.85- 1.36(m) and 0.22-0.39(m) respectively for all modeled arch.

Table1. Concrete characteristics [3]

Density(ρ) (Kg/m^3)	Elastic Modulus (MPa)	Poisson Ratio (υ)
2400	3.1×10^4	0.2

Table 2. Effective coefficient in non elastic and nonlinear analysis [3]

Allowable Tension Stress(f_t) N/mm^2	Allowable Compressive Stress(f_c) N/mm^2	Modulus Of Rupture N/mm^2
2.4	28	4.1

3. SHORT HISTORY, FORMAL DEFINITION AND PROPERTIES OF CELLULAR AUTOMAT

Cellular automata is the computational model which cam simulate the process of growth by describing a complex system by simple individuals following simple rules. This concept of simulation growth was introduce by John Von Neumann [12] and subsequently developed by other researchers in many field of science [10, 1,118]. He was interested to male relation between new computational device - automata theory - and biology. His mind was preoccupied with generating property in natural events [14]. He proved that CA can be general. According to his findings, CA is a collection of cells with reversible states and ability of computation for every thing. Although Van rules were complicated and didn't strictly satisfy computer program, but he continues his research in two parts: for decentralizing machine which is designed for simulation of desirable function and designing of a machine which is made by simulation of complicated function by CA [15]. Wolfram has conducted some research on problem modeling by the simplest and most practicable method of CA architecture too. In 1970,"The Game of Life" introduced by Conway and became very widely known soon. At the beginning of 1980, Wolfram studied one-dimension CA rules and demonstrated that these simple CAs can be used in modeling of complicated behaviors [16, 17].

3.1 Definition

CA is characterized by (a) cellular space (b) transfer rule [12].
For CA , cell, the state of cell in time t, sum of neighbors state at time t and neighborhood radius are denoted by i, S_i^t , η_i^t and r, respectively. Also, the rule is function of $\phi(\eta_i^t)$.

3.2 Change state rules

Each cell changes its state, spontaneously. The primary quality of cells depends on primary situation of problem. By these primary situations, CA is a system which has certain behavior by local rules. The cells which are not neighbors, have no effect on each other.CA has no memory, so present state defines the next state [18].
Quadruple CA is as CA= (Q, d, V and Φ), where Q, d, V and Φ are collection of possible state, CA dimension, CA neighborhood structure and local transferring rule, respectively.
For 1-d CA, amount of i cell (1≤i≤n) at t is shown by $a_i(t)$ and is calculated by this formula:

$$a_i(t+1)= \Phi\ [a_{i-1}(t), a_i(t), a_{i+1}(t)]$$

In this formula, if Φ is affected by the neighbors, it is general. If Φ is a function of neighbor's cell collection and central cell, it is totalistic.

$$a_i(t+1)= \Phi\ [a_{i-1}(t), a_i(t), a_{i+1}(t)]$$

Fig. 3 shows an example of typical neighborhoods for one and dimensional cellular automata.

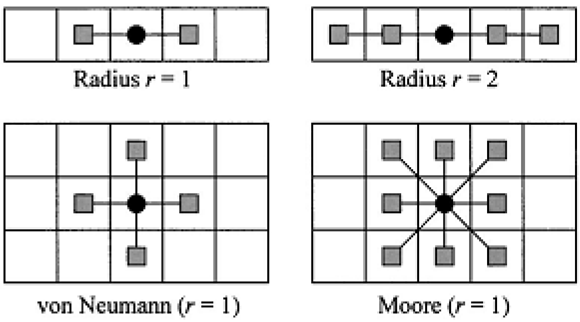


Fig.3. typical neighborhoods for one and two dimensional cellular automata

4. ARCH MODELING USING CA

According to definition of neighborhood radius and state reversal rule in three state 1-d CA, the data for each arch will be analyzed to find the rules of simulation of arch behavior. To achieve this aim,50 to 200 samples of each arch radius, base and top thickness and maximum tensile stress were chosen and analyzed by two and three state algorithm (figure 4 defines two state algorithm completely). After one billion accomplishments, for 256 two-state rules and one million three-state rules, some models were provided for each arch. For example, figures 5 and 6 define semicircular rules and tensile stress efficiency, respectively.

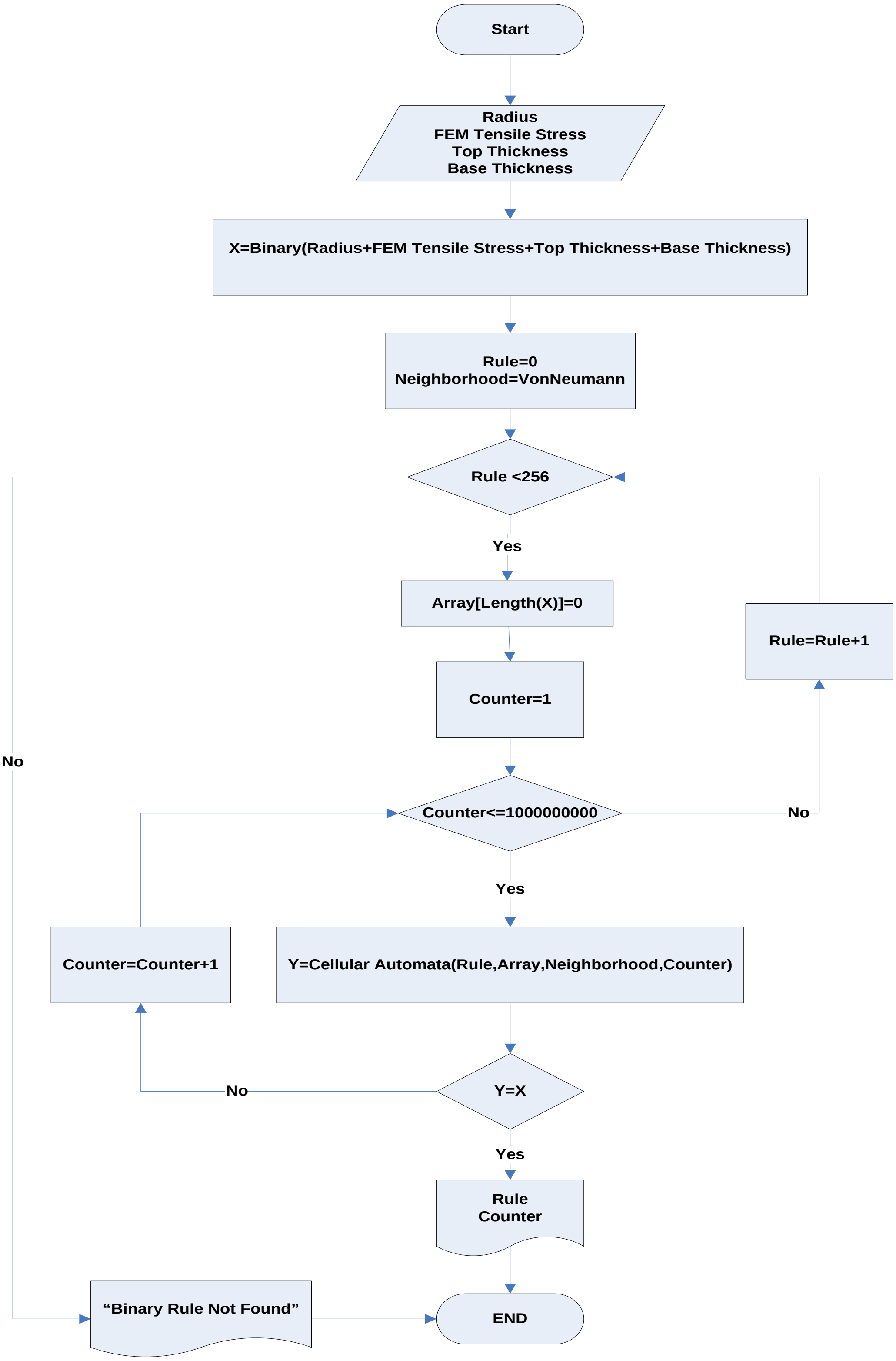


Fig.4. An algorithm for finding two- state 1-D cellular automata model for arch behavior modeling

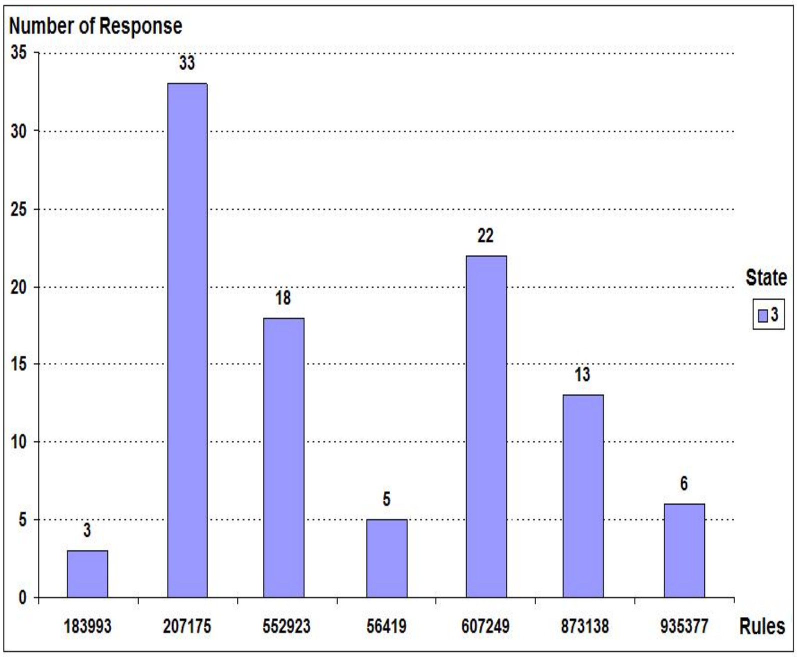


Fig.5. Diagram of three-state rules of cellular automata and some of samples in semicircular arch

5. TEST OF CELLULAR AUTOMATA MODEL

Maximum tensile stress for 50 to 200 samples (according to algorithm in figure 6) has been provided. The error percent has been compared with another analyzed model in FEM software.

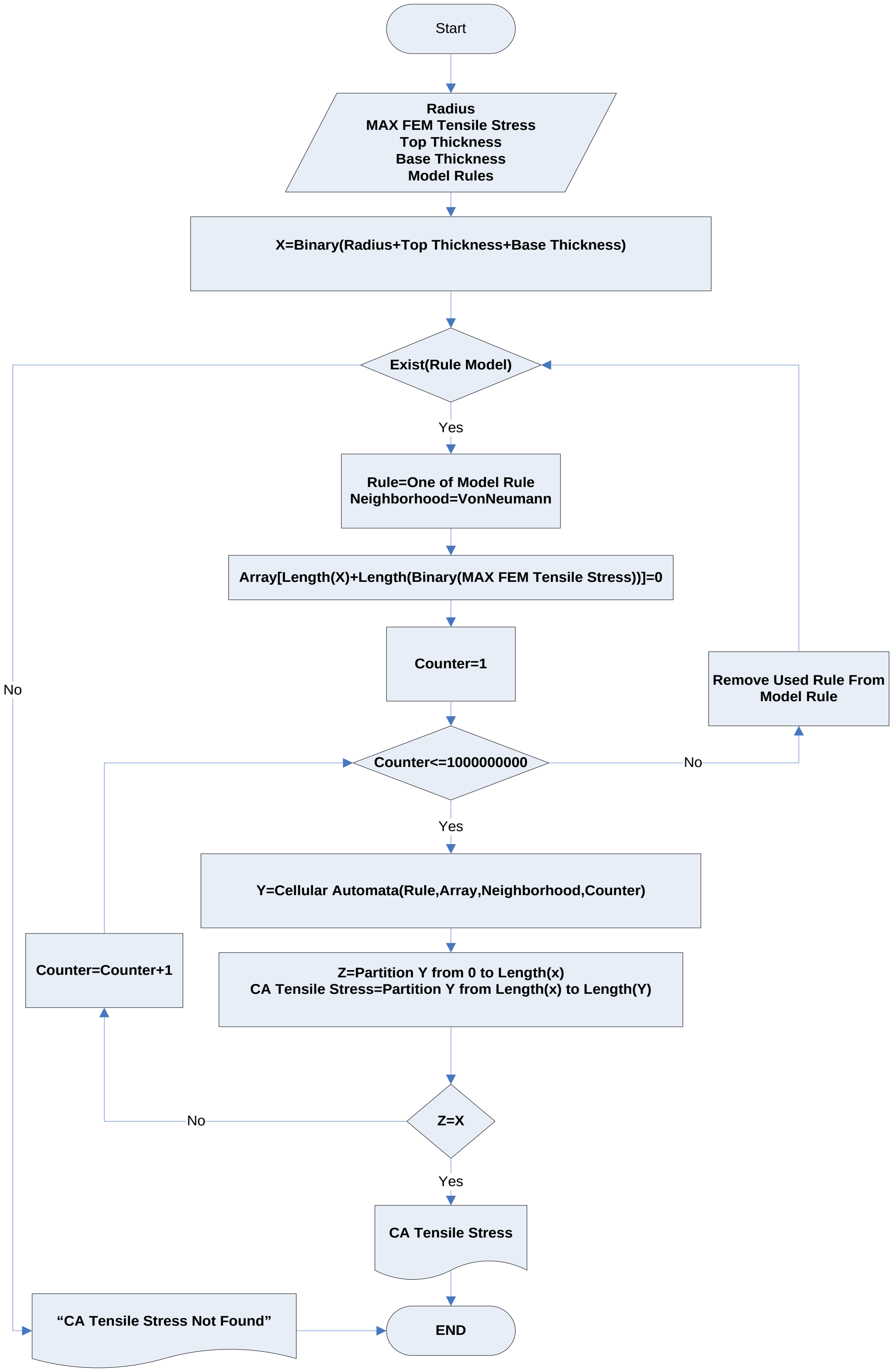


Fig.6. An algorithm for analysis of arch behavior using two-state 1-D CA for maximum tensile stress

5.1 Test Of CA Model For Semicircular

Maximum tensile stress was achieved for 50 to 200 samples of semicircular arches by CA. Figure 7 define comparison between maximum tensile stress in FEM and CA model**.** The mean of error percent in semicircular arch is 12.485%. Figure 8 represent error percent of each sample.

Moreover, Fig. 9 illustrates the diagram of comparison between time of maximum tensile stress computation using CA and FEM software, respectively.

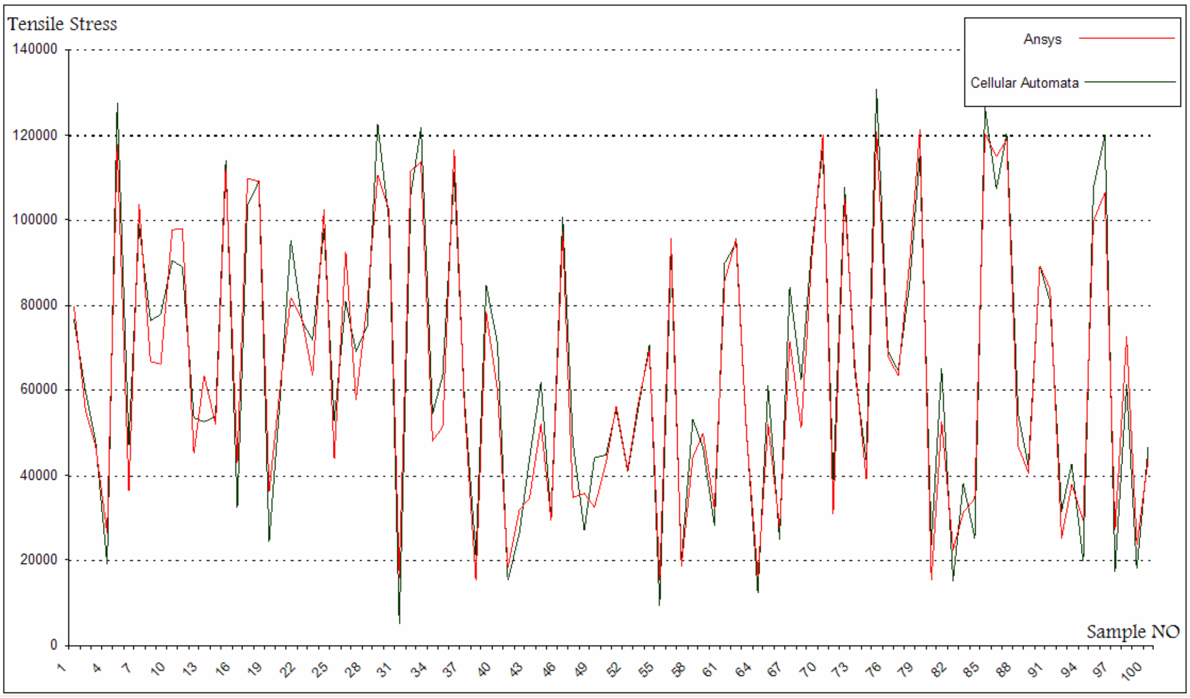


Fig.7. Comparison between maximum tensile stress using FEM software and CA model in semicircular arch

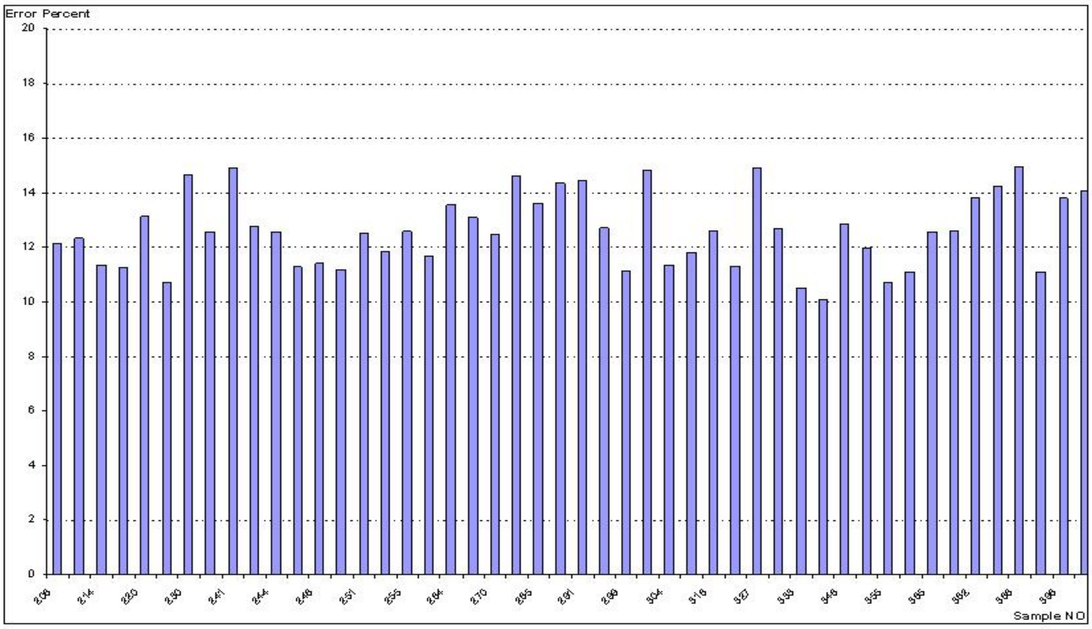


Fig.8. Error percent of maximum tensile stress computation by CA to FEM software in semicircular arch

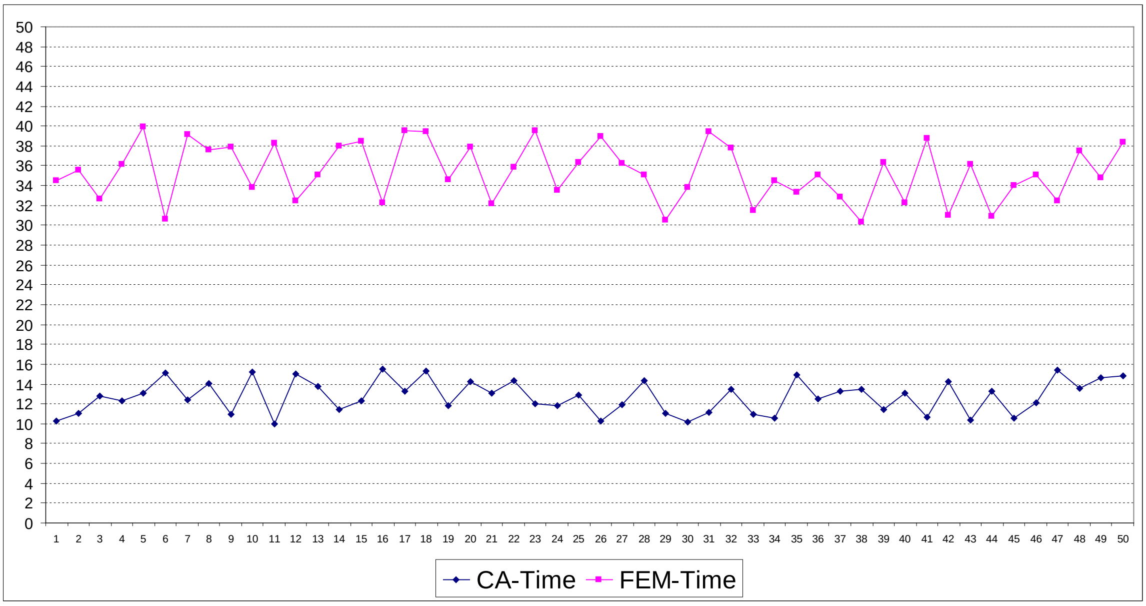


Fig.9. Comparison between time of computation of maximum tensile stress by FEM software and CA

6. ARCH OPTIMIZATION USING CA

In this stage, by means of CA model for each arch top and base thickness were optimized. Considering optimized maximum tensile stress which is 4100(KN/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 (arch base thickness optimization is defined in figure 10).

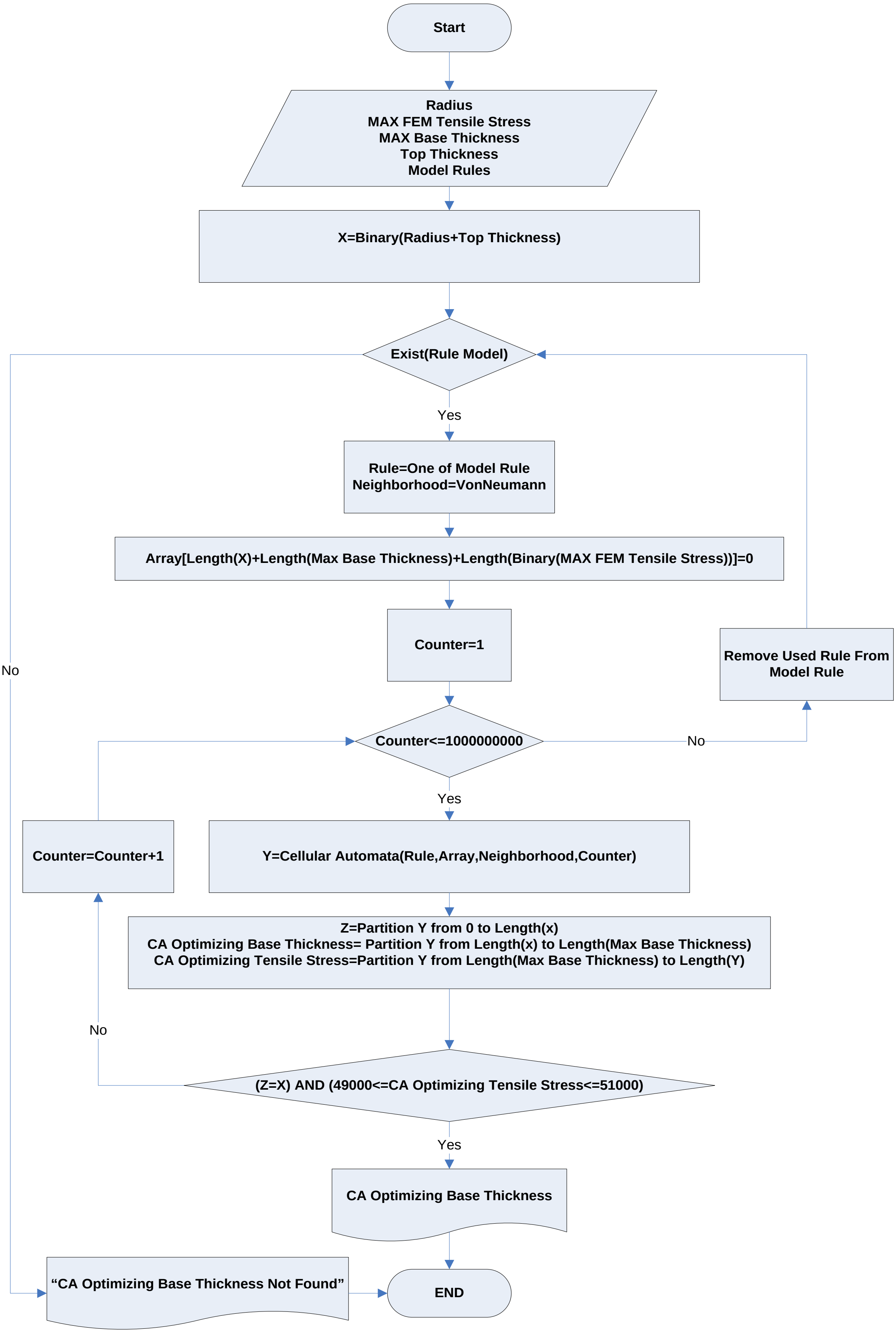


Fig.10. Algorithm of arch thickness optimization using two -sate -1-D cellular automata

6.1 TOP THICKNESS OPTIMIZATION IN SEMICIRCULAR ARCH USING CA

In this stage, 50 to 200 semicircular arch samples were chosen for top thickness optimization. Their optimum maximum tensile stress range, arch radius and base thickness were 4000 to 4100 (KN/m^2) , 4 to 8 meter and 0.85 to 1.36, respectively. After ward, the top thickness was calculated and compared with top thickness in FEM software (fig.13). The mean of error percent of top thickness calculation was 12.339%. Figure 11 and 12 show error percent of each sample in CA toward FEM software and comparison of optimization time of top thickness optimization in semi circular arch.

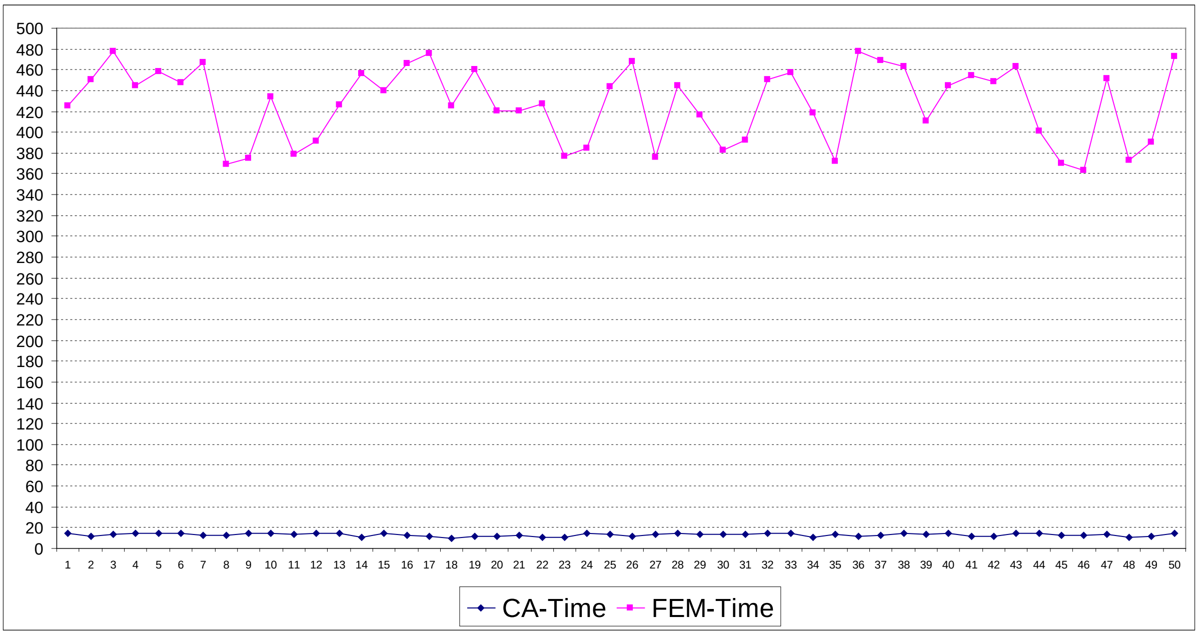


Fig.11. Comparison between maximum tensile stress of semicircular arch using FEM software and CA model

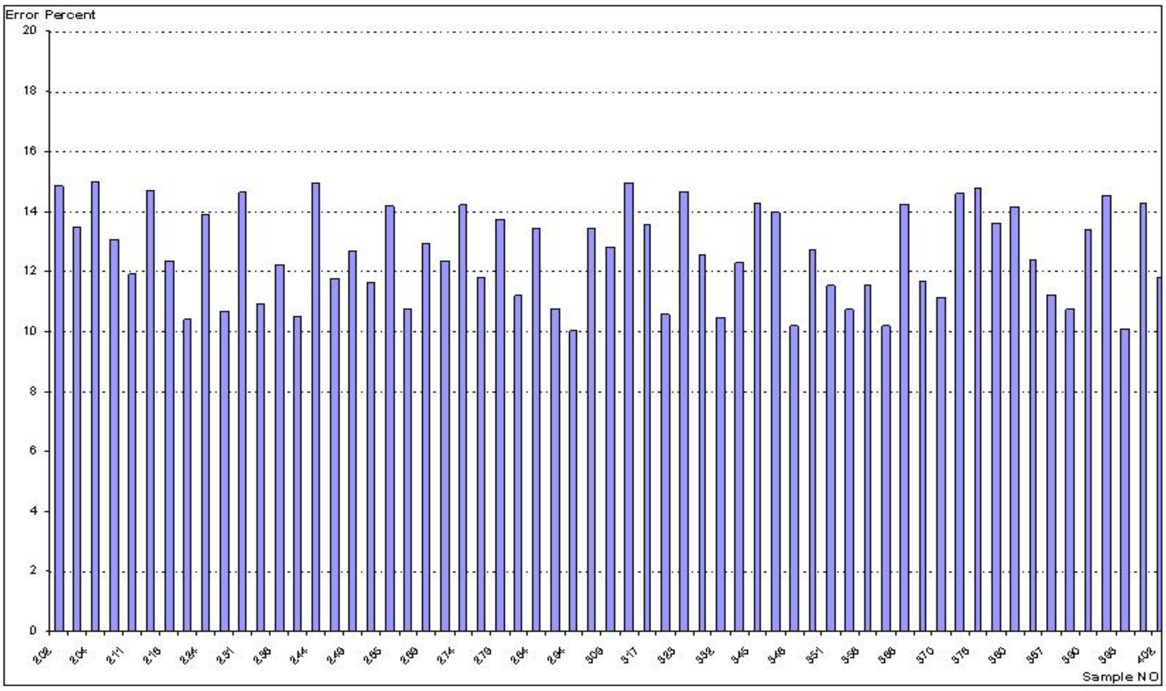


Fig.12. Error percent of top thickness optimization in semicircular arch using CA model towards FEM software

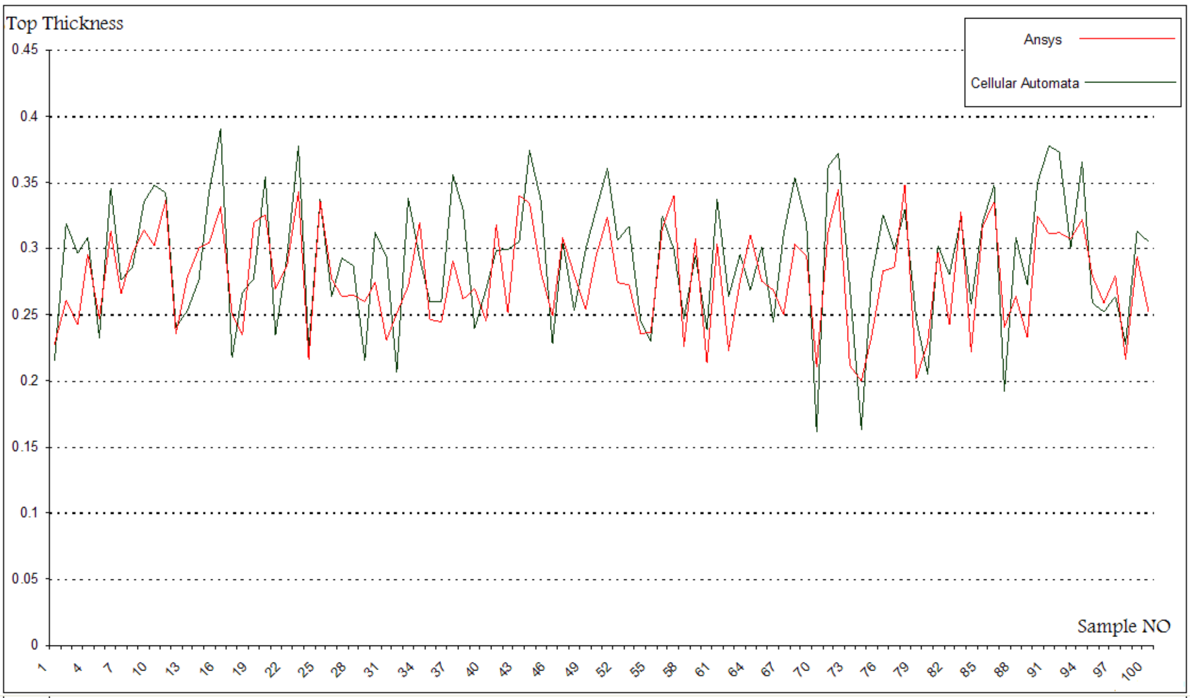


Fig 13.Comparison of optimum range of arch top thickness using CA model and FEM software

6.2 Basic Thickness Optimization In Semicircular Arch Using CA

In this section, 50 to 200 semicircular arch samples were chosen for top thickness optimization. Their optimum maximum tensile stress range, arch radius and base thickness were 4000 to 4100(KN/ m^2), 4 to 8 meter and 0.22 to 0.39, respectively. After calculation of base thickness- according to algorithm in figure 10, the results were compared with base thickness in FEM software (fig.16). The mean of error percent of base thickness calculation was 13.74%. Figure 14 and 15 show error percent of each sample in CA toward FEM software and comparison of optimization time of base thickness optimization in semi circular arch.

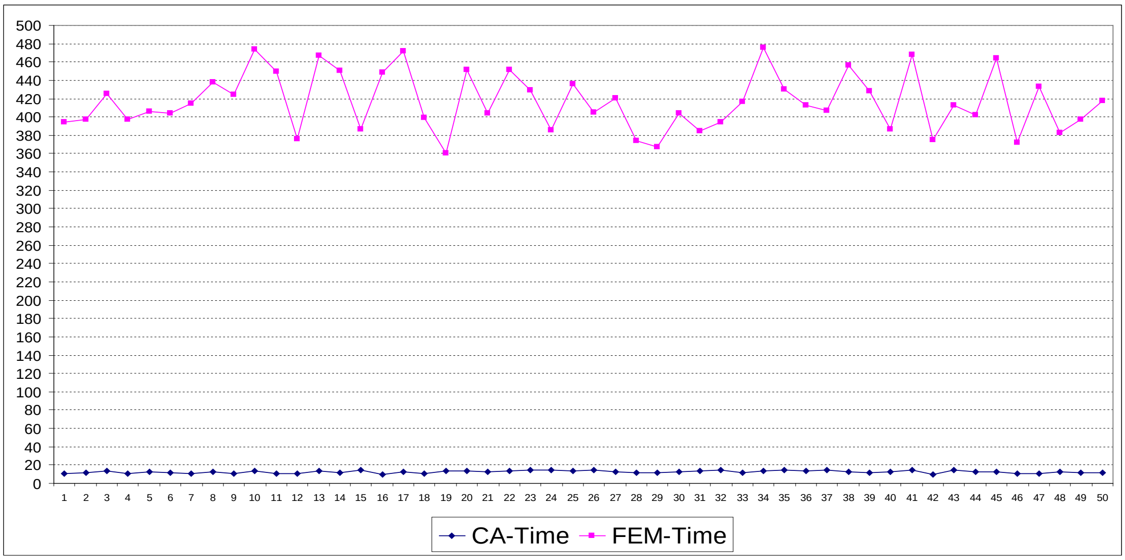


Fig.14. Comparison between optimization time of base thickness in semicircular arch using FEM software and CA model

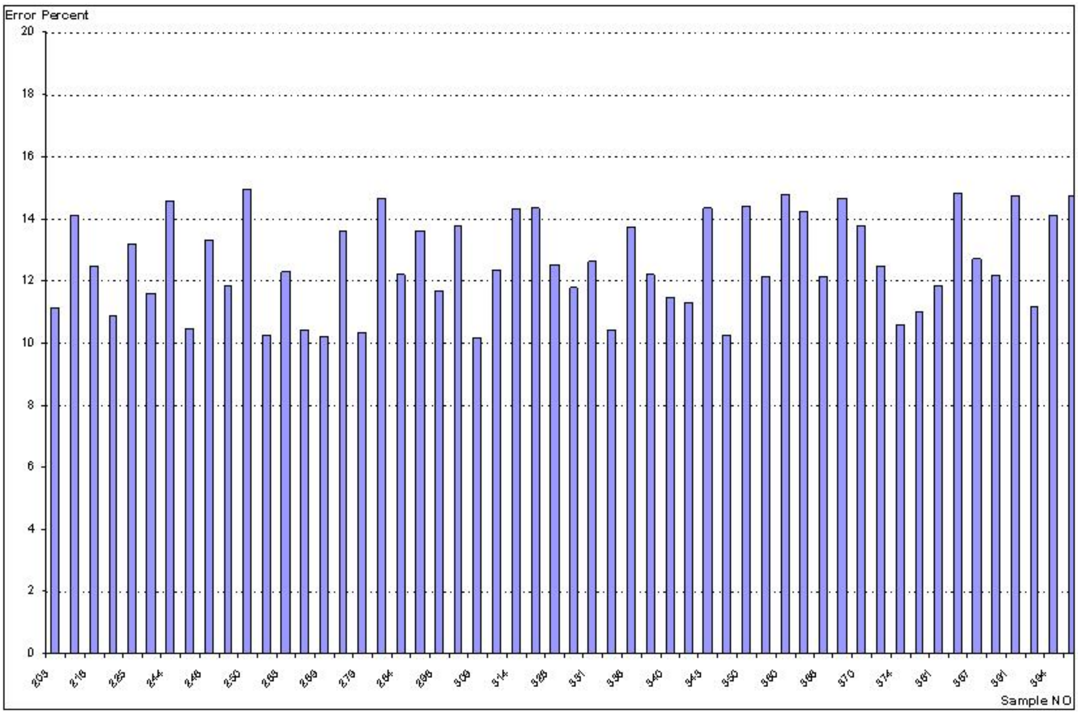


Fig.15. Error percent of base thickness optimization in semicircular arch using CA model towards FEM software

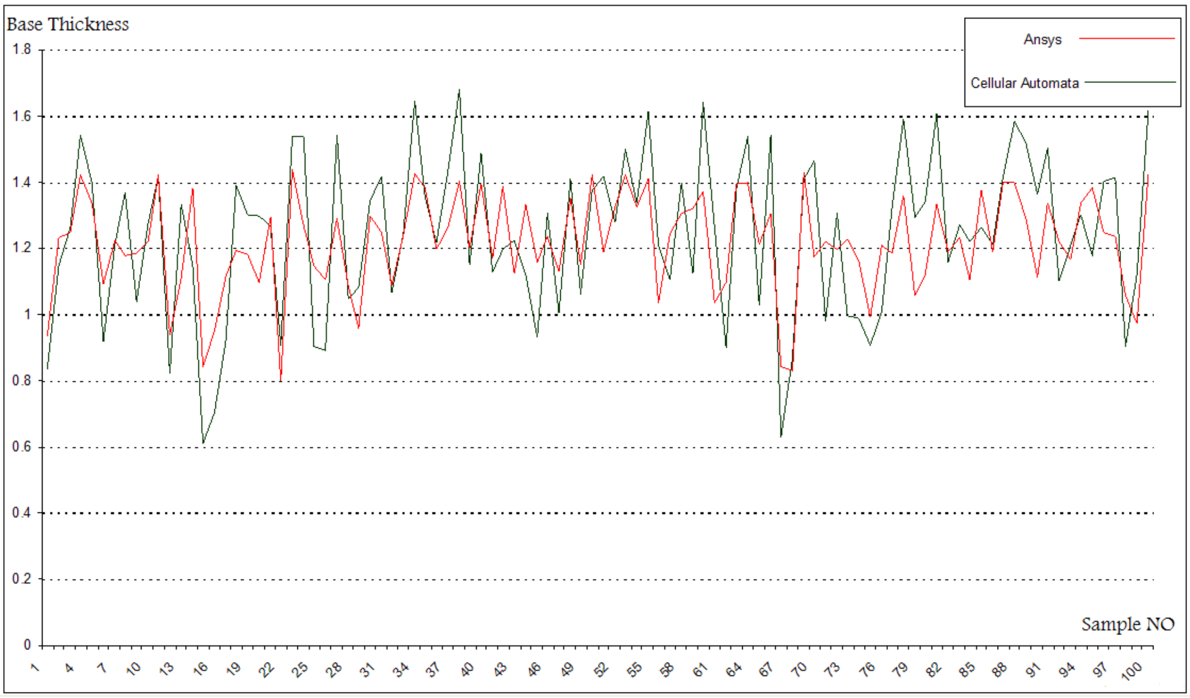


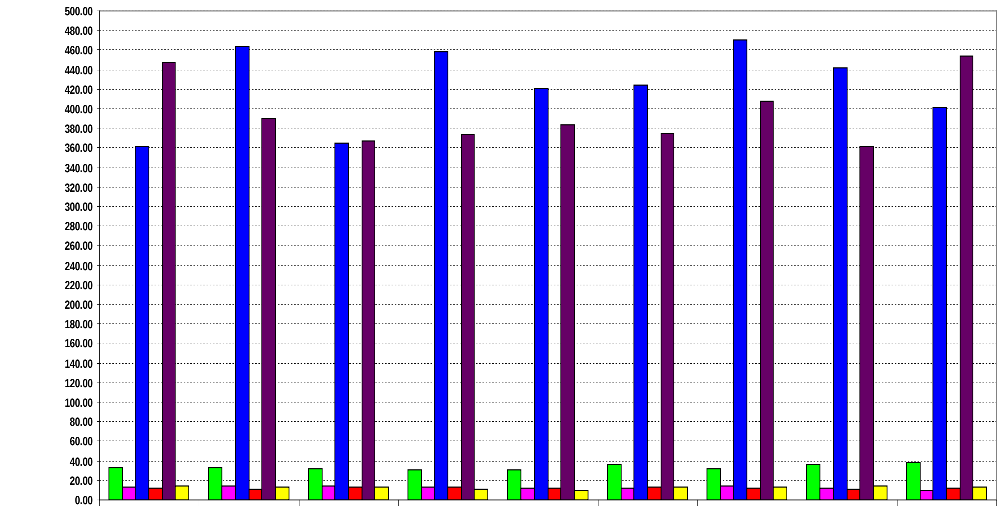
Fig.16. Comparison of optimum range of arch base thickness using CA model and FEM software

7. CONCLUSION

The approach presented in this paper aims to overcome the previous drawbacks. The principal novelty of this research is the use of a special class of evolutionary algorithms, called Cellular Automata.

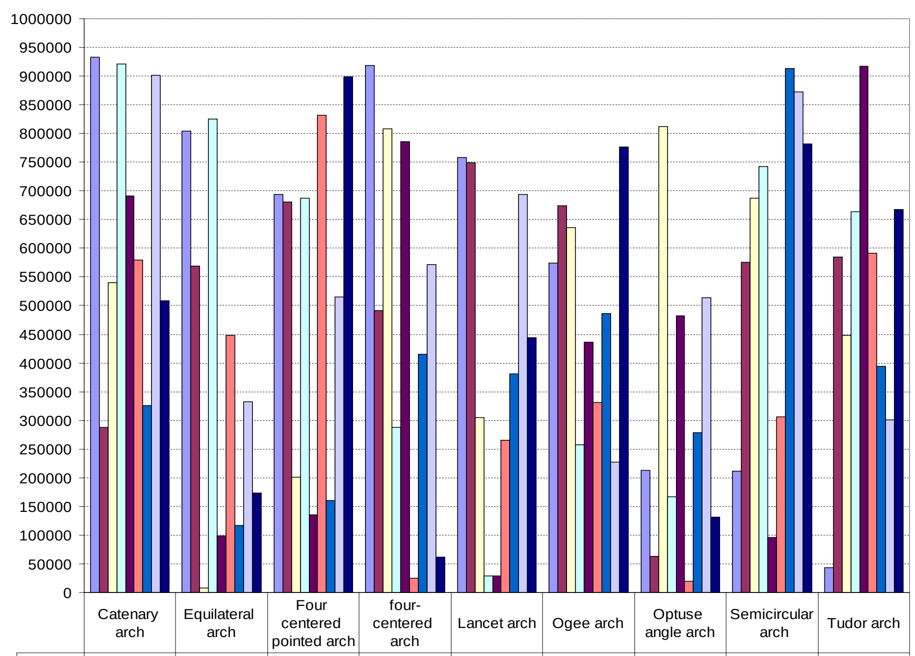
In the present paper, nine arches- semi-circular, obtuse angel, four- centered pointed; Tudor, ogee, equilateral, catenaries, lancet and four-centered arches- were modeled using FEM software and CA model. Figures 17, 18 and 19 show analysis and optimization time, the results which are provided

by CA in arch modeling and the mean of error percent for arch analysis and its optimization, respectively.
Considering the results, CA 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 models precision, the rules which are larger than 1000000 and repeated more than 1000000000 times are needed.



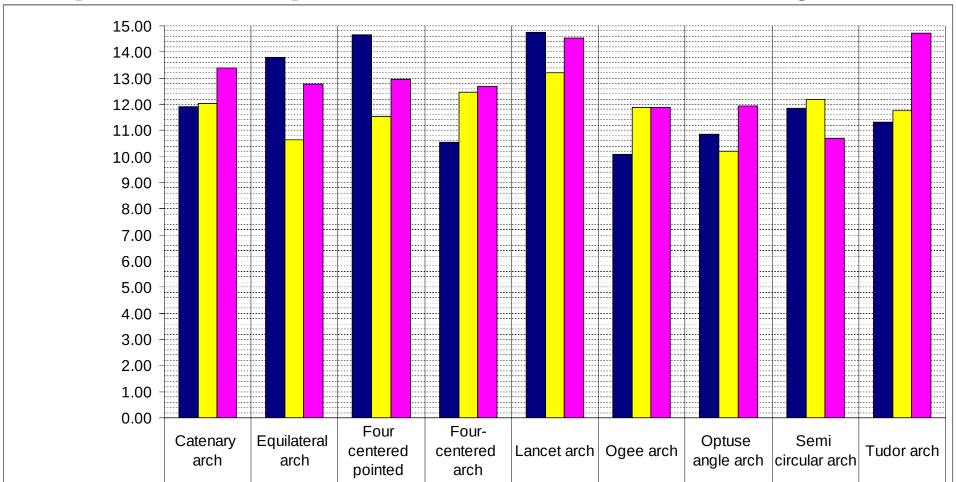
	Semicircular arch	Optuse angle arch	Ogee arch	Tudor arch	Four centered pointed arch	Equilateral arch	Catenary arch	Lancet arch	four-centered arch
FEM Analyzing Average Time	32.49	32.95	31.49	30.39	30.72	36.14	31.88	35.82	38.86
CA Analyzing Average Time	13.16	14.31	14.15	13.50	12.17	12.25	14.35	12.24	10.05
FEM Top Thickness Optimizing Average Time	361.95	464.19	364.93	458.70	420.60	424.00	470.16	442.18	401.55
CA Top Thickness Optimizing Average Time	12.46	11.23	13.49	13.54	12.20	13.26	12.22	10.68	12.50
FEM Base Thickness Optimizing Average Time	447.76	390.02	366.87	373.95	383.81	375.03	407.68	361.42	454.18
CA Base Thickness	14.19	13.21	13.49	10.69	10.03	13.73	13.68	14.72	12.75

Fig.17. Comparison between mean of analysis and optimization time of all discussed arches using FEM software and CA model



	Catenary arch	Equilateral arch	Four centered pointed arch	four-centered arch	Lancet arch	Ogee arch	Optuse angle arch	Semicircular arch	Tudor arch
Rule 1	933304	804103	693280	918955	758648	573614	212651	211772	42834
Rule 2	287655	569347	680187	491932	749528	674469	63569	575079	584831
Rule 3	539999	8513	201062	807554	305005	635596	812311	687505	448701
Rule 4	921015	825080	686830	288260	29205	256940	166736	742208	663835
Rule 5	691301	98082	135216	786089	28294	436585	482617	96337	917766
Rule 6	579317	447681	831812	24570	265198	330518	20367	305994	591319
Rule 7	325380	116635	159984	415444	380722	485588	278401	913763	394863
Rule 8	901777	332203	515608	571547	693331	227163	513241	872347	300775
Rule 9	508423	173822	898608	62111	443698	776822	131367	782117	667580

Fig.18. Comparison between provided rules for discussed arches using cellular automata



	Catenary arch	Equilateral arch	Four centered pointed	Four-centered arch	Lancet arch	Ogee arch	Optuse angle arch	Semi circular arch	Tudor arch
Base Thickness Error Percent AVG	11.90	13.80	14.67	10.56	14.76	10.09	10.87	11.83	11.31
Tensile Stress Error Percent AVG	12.04	10.64	11.52	12.46	13.21	11.87	10.21	12.20	11.74
Top Thickness Error Percent AVG	13.38	12.77	12.95	12.68	14.53	11.88	11.93	10.71	14.73

Fig.19.Comparison between the mean of error percent of analysis of tensile stress and optimization of base and top thickness for discussed arches using CA model toward FEM software

References

[1] C. Adami, Introduction to artificial life, (1998), Springer, New York.

[2] A. Gupta, S .Taylor, J. Kirkpatrick, A.Long and I.Hogg, A Flexible Concrete Research In Ireland Colloquium, (2005).

[3] ASTM STP 169B. Significance Of Tests And Properties Of Concrete And Concrete-Making Mate Rials, (1978).

[4] M. Baei, M. Ghassemieh, A. Goudarzi, "Numerical modeling of end- plate moment connection subjected to bending and axial forces", the journal of computer and mathematic science, (2012) Vol.4, No.3, 463-472.

[5] B.Ozden Caglayan, Kadir Ozakgul and Ovunc Tezer, assessment of concrete arch bridge using static and dynamic load tests, structural engineering and mechanics, (2012) Vol.41, No.1, PP.83-99.

[6] C. Franciosi, A Simplified Method For The Analysis Of Incremental Collapse Of Reinforced Concrete Arches, (1984), To Appear In Int. J. Mech. Sci.

[7] J. Heyman, The Masonry Arch, (1982), Ellis Harward- Wiley, West Sussex, UK.

[8] K. Kumarci, A. Ziaie, Optimum Shape In Brick Masonry Arches Under Static And Dynamic Loads., International Journal Of Mathematics And Computers In Simulation, Wseas Transactions On Mathematics , (2008)Volume 7, Issn: 1998-0159, 171-178.

[9] K. Kumarci, P. Khosravyan, Optimum Shape In Brick Masonry Arches Under Dynamic Loads By Cellular Automata., Journal Of Civil Engineering (IEB), 37 (1) (2009) 73-90.

[10] N. Margolus, T. Toffoli , Cellular Automata Machines. A New Environment for Modeling, (1987), MIT Press, Cambridge, Mass.

[11] N. Moarefi, N., A. Yarahmadi, Implementation of Cellular Automata with non- identical rule on serial base, the journal of mathematic and computer science, (2012) Vol. 4, No. 2, 264- 269.

[12] A. Moore, New Constructions In Cellular Automata, (2003), Oxford University Press.

[13] V. Neumann, The General and Logical Theory of Automata, (1963), in J. Von Neumann, collected works, edited by A.H.Taub.

[14] V. Neumann, Probabilistic Logics And The Synthesis Of Reliable Organisms From Unreliable Components, (1993),Von Neumann's Collected Works, A. Taub (Ed).

[15] V. Neumann, , The Theory Of Self-Reproducing Automata, (1996), A. W. Burks (Ed), Univ. Of Illinois Press, Urbana And London.

[16] S. Wolfram, Statistical Mechanics Of Cellular Automata, (1983), Rev. Mod. Phys.

[17] S. Wolfram, Universality And Complexity In Cellular Automata, (1984),, Physical D.

[18] S. Wolfram, A New Kind Of Science, Wolfram Media, (2002), Champaign, III.