FORECAST OF COLLAPSE MODE IN ECCENTRICALLY PATCH LOADED STEEL I-GIRDERS BY MEANS OF ARTIFICIAL NEURAL NETWORKS

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ABSTRACT

Particularly intriguing problem in structural engineering practice is eccentric patch loading - thin-walled steel I-girder loaded over flange by local load having a certain eccentricity regarding the web plane. Depending on girder geometry and load eccentricity, eccentrically patch loaded girders might have collapse mode and collapse load the same as centrically loaded girders (i.e. as if there is no eccentricity) or completely different collapse mode than in case of centric load, with reduced collapse load due to load eccentricity. It is essential to know collapse mode of eccentrically loaded girder in order to determine its collapse load.

Patch loading research projects at the University of Montenegro, among extensive experimental research and different theoretical research ways, included application of artificial neural networks (ANN) for solving simultaneous problems of determination of collapse mode and collapse load in eccentrically locally loaded steel I-girders. Presented example of ANN modelling proves possibility of successful and useful application of this method in engineering practice. Not only that such models might be used to forecast collapse mode of particular girders. They might also help in establishing general criteria for collapse mode identification in eccentrically patch loaded girders. However, further work in this domain is welcome. Even available experimental database, which was used for network training in presented example, might provide different and better results through: another choice of numerical values for collapse mode types instead of values chosen in the presented example; another choice of data for comparison, training and validation sets; another choice of artificial neural network architecture and training process; use of another computer software. Any future experimental or numerical (e.g. finite element method) modelling will provide extension of database, enabling creation of ANN forecast models with better results.

The fact that ANN modelling method belongs to the domain of artificial intelligence should be kept in mind, since such methods should be strongly controlled by human intelligence in order to give results that comply with the reality.

Keywords: Eccentric patch load, steel I-girder, collapse mode, forecast model, artificial neural network.

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1. INTRODUCTION

Patch loading is the loading that acts locally, over a small area or length of a structural element. Particularly intriguing problem is the case when the load affects the flange of a steel I-profile so that the web, below the loading, is locally pressed. Patch loaded girders are widely used in engineering practice: crane girders loaded by the crane wheels, bridge girders erected by launching etc.

A series of experimental researches analysing patch loading problems was organised at the University of Montenegro, since 1998 (Lučić 1999; Šćepanović 2002; Šćepanović 2009). Among the other issues, particular attention was paid to the problem of eccentric patch loading, having in mind that a certain eccentricity of load, regarding the web plane, is unavoidable in real structures. Figure 1 shows tested girder(s) with characteristic dimensions. Girder span, a, web depth, h_w, and flange width, b_f, were same in all tested girders ($a = h_w = 700$ mm, $b_f = 150$ mm). Web thickness, t_w, flange thickness, t_f, as well as load eccentricity, e, were variables ($t_w = 3 \div 10$ mm, $t_f = 3 \div 15$ mm, $e = 0 \div 30$ mm), making also variable influential parameters such as t_f/t_w, e/b_f, b_f/t_f, a/t_w ($= h_w/t_w$).

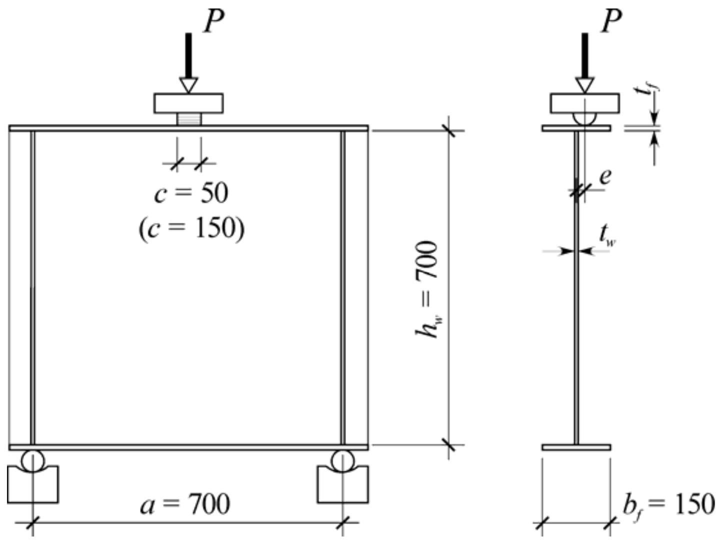


Figure 1: Experimentally tested I-girder(s) under eccentric patch loading

For the analysis of eccentric patch loading, 144 tests were done in experiments from 1998 (Lučić 1999), 2001 (Šćepanović 2002) and 2007 (Šćepanović 2009). Girders are grouped in series, by the dimensions. Six girders of same geometry make one series where load eccentricity varies in range from $e = 0$ to $e = b_f/6 = 25$ mm. A few girders were also tested with eccentricity $e = 30$ mm. Most girders were loaded over the length $c = 50$ mm, while several samples had load length $c = 150$ mm.

It was shown that the collapse mode of most (but not all!) girders subjected to eccentric patch loading was quite different from the collapse mode of centrically loaded girders. Three different collapse modes are observed in experimentally tested eccentrically patch loaded steel I-girders: eccentric, centric and mixed collapse mode. Mixed collapse mode, having characteristics of both, centric and eccentric collapse modes, may appear in two variants: as centric-mixed or as eccentric-mixed collapse mode, depending on dominant collapse mode characteristics.

Concerning engineering practice, the most important difference between collapse modes is in ultimate load. The reduction in ultimate load with an increase in load eccentricity is obvious in girders with eccentric collapse mode. For a certain girder geometry, even the smallest load eccentricity ($e = 5$ *mm*, i.e. $e/b_f = 1/30$ in tested girders) reduced ultimate load over 40%. In case of centric collapse mode in eccentrically loaded girders, ultimate load does not change significantly with an increase in load eccentricity. Even for the highest load eccentricity ($e = 25$ *mm*, i.e. $e/b_f = 1/6$ in tested girders), girders of certain geometry behaved as if there was no eccentricity.

Hence, in order to estimate ultimate load, the first step is to determine collapse mode of eccentrically loaded I-girder. Influential parameters are numerous, mutually dependant and related: girder geometry (all dimensions of girder and their ratios), load eccentricity and its relations with girder dimensions, as well as load application manner. Dealing with such a big number of correlated influential parameters, makes determination of collapse mode and calculation of collapse load difficult tasks. One approach that was analysed is application of artificial neural networks (ANN).

2. ANN MODELLING OF EXPERIMENTALLY TESTED GIRDERS

Although the problems of collapse mode determination and collapse load calculation are mutually connected, collapse mode qualifying the level of collapse load, for the beginning these two issues are considered independently from each other. At first, artificial neural network (ANN) modelling was implemented in estimation of collapse load, without considering collapse mode. Latter on, the same networks, that gave good results in estimation of collapse load, were slightly modified, adapted and used to forecast collapse mode.

2.1. Forecast models for collapse load

The basic idea was to estimate the collapse load, P_u, as the only output parameter, depending on numerous input parameters (material characteristics, girder geometry and load eccentricity), as well as to asses applicability of ANN modelling method for collapse load determination in engineering practice.

Several types of forecast models were made using experimental data from 1998, 2001 and 2007: with dimensional (e.g. e, t_f, t_w) and dimensionless (e.g. e/b_f, e/t_f, e/t_w, b_f/t_f, t_f/t_w, h_w/t_w) geometry inputs. Several types of network architecture were constructed: with one or two hidden levels of neurons; with different number of neurons (1 to 20) in each level, depending on inputs number and number of training data. Later on, comparison of different forecast models was done in order to evaluate which models provide the best forecast of collapse load. Afterwards, these best models were used for assessing applicability of ANN modelling method in engineering practice, as a tool for determination of collapse load in eccentrically patch loaded steel I-girders.

The same one computer software (Knežević 2004; Šćepanović 2009) was used for training of all created artificial neural networks, i.e. all ANN forecast models are obtained by means of the same software, using the same experimental data base, consisting of 144 tested girders.

ANN models were made separately for girders with different load lengths ($c = 50$ or 150 *mm*). Herein only load length of $c = 50$ *mm* and models with five dimensional inputs (e, t_w, t_f, $\sigma_{0.2,w}$ – web yielding stress, $\sigma_{0.2,f}$ – flange yielding stress) and one output (P_u) are considered. The complete experimental data set for girders with load length $c = 50$ *mm* consists of 120 tested girders. 19 tests were exempted from the network training process and used as a comparison data set, i.e. as data for the evaluation of forecast models. The rest of 101 tests were divided in training data set (71 tests) and validation data set (30 tests). The best evaluated models show high level of match with experimental data and prove to be acceptable and confident for engineering practice.

2.2. Forecast models for collapse mode

The same networks created for collapse load estimation, after appropriate adaptation, were used for the collapse mode forecast. Input parameters and network architecture were kept the same. Only output parameter was changed. Collapse mode was introduced instead of collapse load and the same iterative network training process was done again, with the new output. Comparison, training and validation data sets were the same as for collapse load models.

In order to use available software (Knežević 2004; Šćepanović 2009) for network training, it was necessary to transform collapse mode, being alpha-numerical, descriptive parameter, in the form of numerical parameter. Each type of collapse mode was assigned a numerical value from the interval [-1, 1]: centric collapse mode = 1; centric-mixed = 0.3; eccentric-mixed = -0.3; eccentric = -1.

Table 1 gives an overview of networks which were trained successfully and provided applicable forecast models for collapse mode of girders with the load length $c = 50$ *mm*. Among created networks, the best results are obtained from network with one hidden level, with six neurons, and from network with two hidden levels, each with 19 neurons. Examples of collapse mode forecast models of these two networks are presented in Figure 2. Four characteristic girder geometry types, i.e. four experimental series, having representative sample in comparison data set, were chosen for this presentation and comparison of ANN modelling of collapse mode with experimental results.

In Figure 2, lines present ANN forecast models for collapse mode, while dots present experimental results. Red dot is the sample from comparison data set. Yellow dots are samples of same geometry, but with different load eccentricity. Each of four diagrams presents one complete experimental series.

Graphical presentation of results is chosen as the most suitable, having in mind character of output parameter – collapse mode. In this manner, visual evaluation of forecast models and assessment of ANN modelling application is enabled.

Generally speaking, presented ANN forecast models match experimental data well, what makes them applicable in practice. Noticeable discrepancy is observed only in case of centric collapse at high eccentricity of load, Figure 2/(3&4). It happens in girders with high ratio t_f/t_w. Only collapse mode for highest eccentricity ($e = 25$ *mm*) is not well forecasted, while ANN models provide good forecast of collapse mode for other eccentricities ($e \leq 20$ *mm*) even in these girders.

Table 1: An overview of created ANNs for the forecast of collapse mode in girders with load length c = 50 *mm*

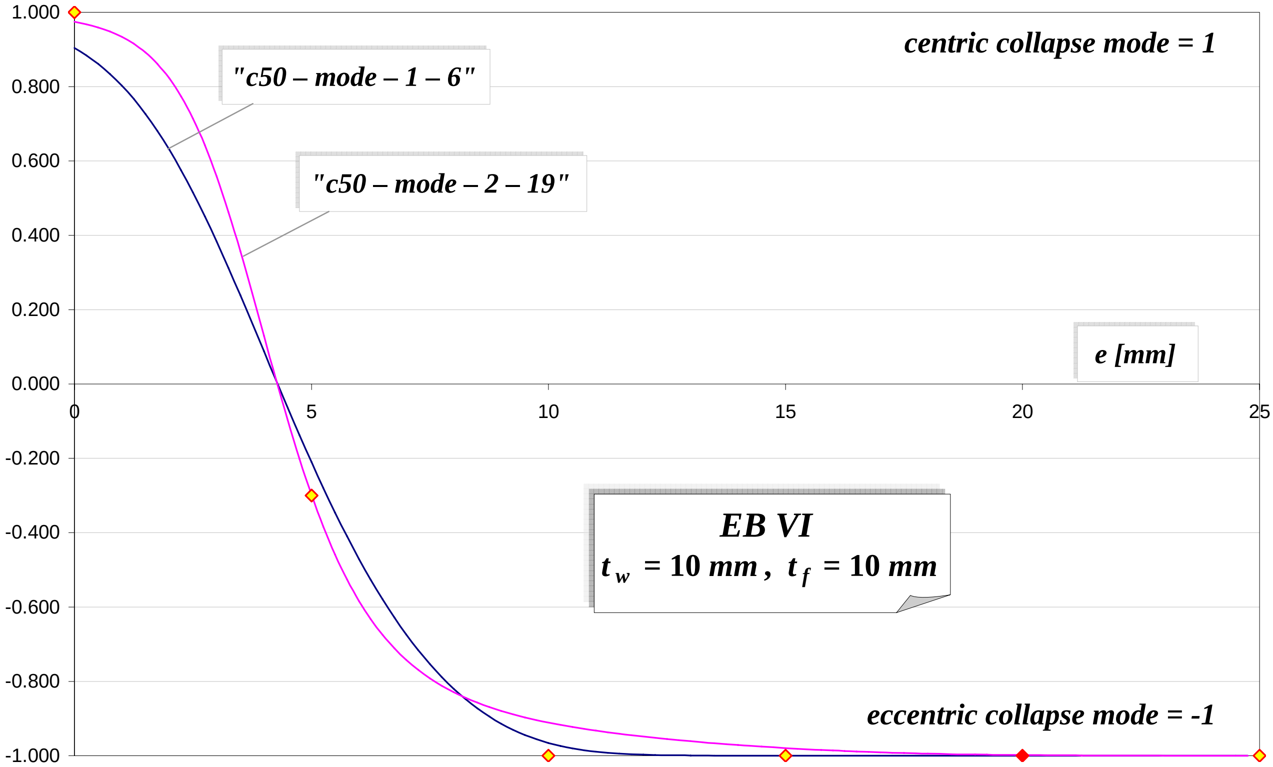
ANN (forecast model) name	*number of hidden levels*	*number of neurons in one level*
(Initial intention was to train all networks used for collapse load estimation. However, some networks, showing obvious and persistent non-adequate behaviour from the early stages of iterative training, were abandoned during the training process.)		
c50 – mode – 1 – 13	1	13
c50 – mode – 1 – 12	1	12
c50 – mode – 1 – 11	1	11
c50 – mode – 1 – 10	1	10
c50 – mode – 1 – 9	1	9
c50 – mode – 1 – 8	1	8
c50 – mode – 1 – 7	1	7
c50 – mode – 1 – 6	1	6
c50 – mode – 1 – 5	1	5
c50 – mode – 1 – 4	1	4
c50 – mode – 1 – 3	1	3

ANN (forecast model) name	*number of hidden levels*	*number of neurons in one level*
c50 – mode – 2 – 20	2	20
c50 – mode – 2 – 19	2	19
c50 – mode – 2 – 18	2	18
c50 – mode – 2 – 17	2	17
c50 – mode – 2 – 16	2	16
c50 – mode – 2 – 15	2	15
c50 – mode – 2 – 14	2	14
c50 – mode – 2 – 13	2	13
c50 – mode – 2 – 12	2	12
c50 – mode – 2 – 11	2	11
c50 – mode – 2 – 10	2	10
c50 – mode – 2 – 9	2	9
c50 – mode – 2 – 8	2	8
c50 – mode – 2 – 7	2	7
c50 – mode – 2 – 6	2	6
c50 – mode – 2 – 5	2	5
c50 – mode – 2 – 4	2	4
c50 – mode – 2 – 3	2	3
c50 – mode – 2 – 2	2	2
c50 – mode – 2 – 1	2	1

3. CONCLUSIONS

Presented example of ANN modelling proves possibility of successful and useful application of this method in engineering practice for the purpose of determination of collapse mode type in eccentrically patch loaded steel I-girders. Not only that such models might be used to forecast collapse mode of particular girders. They also might help in establishing general criteria for collapse mode identification in eccentrically patch loaded girders. One set of such criteria are formulated (Šćepanović 2009), based on existing experimental database. It means that proposed criteria are valid for the domain of experimental data. The question is: what about girders with the dimensions out of experimental data domain? Graphical presentation of ANN models as in Figure 2 might help answering this question. Diagrams in Figure 2 imply points and/or zones of collapse mode types separation in girder of certain geometry, depending on load eccentricity. Zones of centric, mixed and eccentric collapse modes might be identified. By means of such diagrams, adequate ANN forecast models might provide new criteria for collapse mode identification, as well as their validation out of the experimental domain.

Only one example is presented here, aiming picturing reliable results, as well as simple practical application of ANN modelling method in subject problem solving. However, further work in this domain is welcome. Even available experimental database used for network training in this example



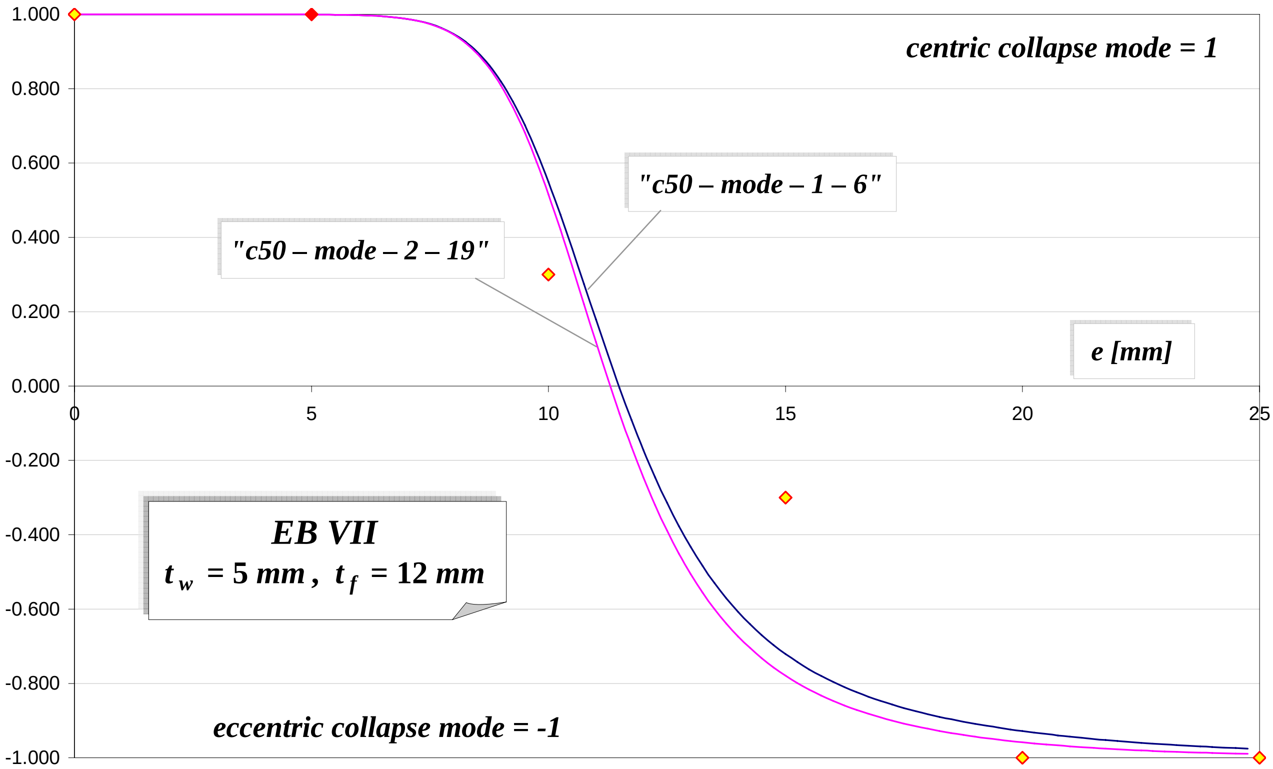
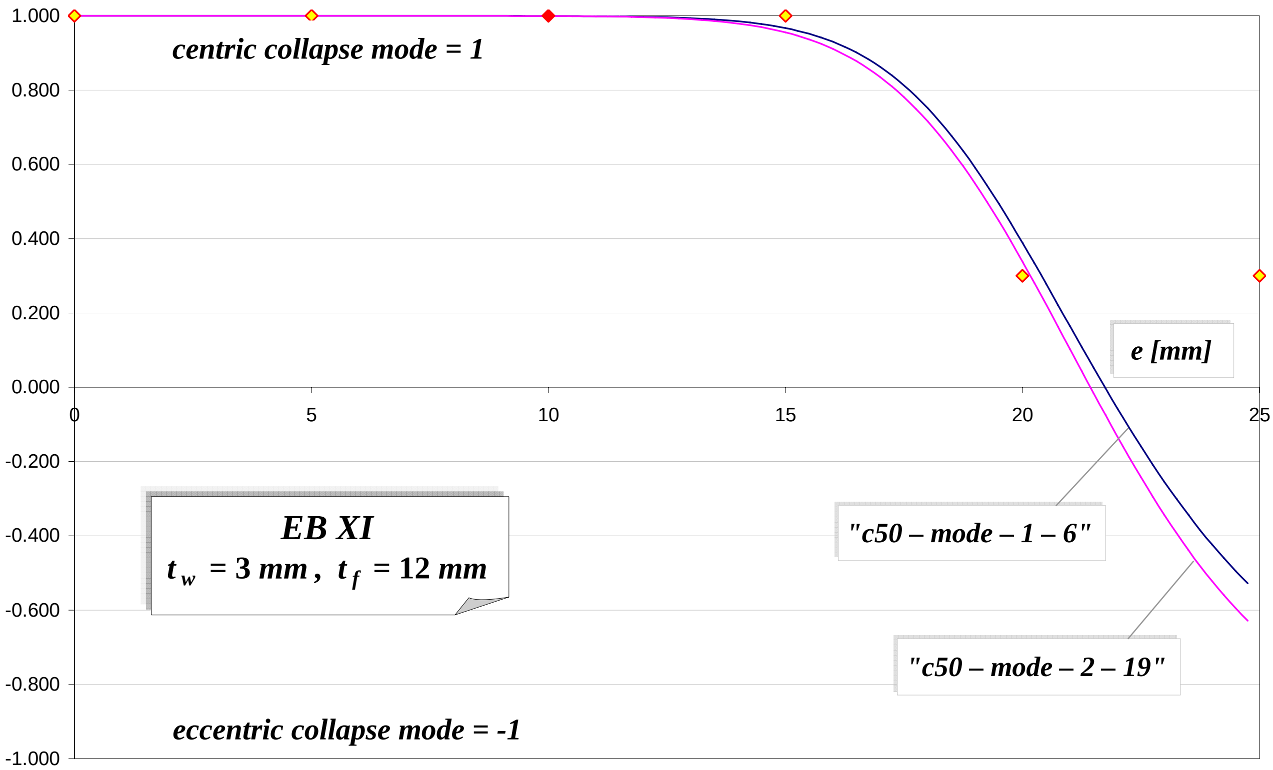


Figure 2/(1&2): Examples of collapse mode forecast models,
for networks *"c50 – mode – 1 – 6"* and *"c50 – mode – 2 – 19"*
(Fig. 2/1 – experimental series *EB VI*; Fig. 2/2 – experimental series *EB VII*)



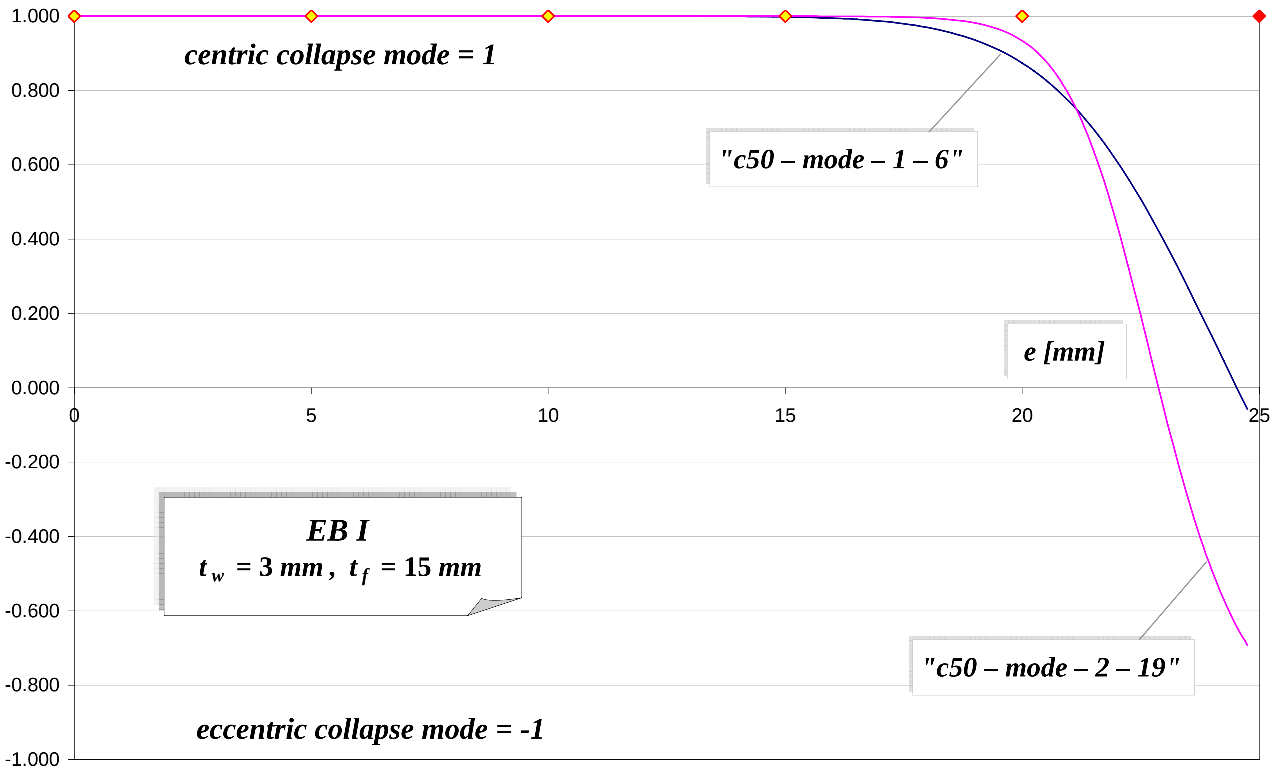


Figure 2/(3&4): Examples of collapse mode forecast models, for networks *"c50 – mode – 1 – 6"* and *"c50 – mode – 2 – 19"* (Fig. 2/3 – experimental series *EB XI*; Fig. 2/4 – experimental series *EB I*)

might provide different and better results. Improvement is possible through: another choice of numerical values for collapse mode types instead of values from the interval [-1, 1], as in presented example; another choice of data for comparison, training and validation sets; another choice of artificial neural network type, i.e. type of its architecture and training process; use of another computer software. Any future experimental or numerical (e.g. finite element method) modelling will provide extension of database, enabling creation of ANN models with better results.

Still, the fact that ANN modelling method belongs to the domain of artificial intelligence, should be kept in mind, since such methods should be strongly controlled by human intelligence in order to give results that comply with the reality.

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