Application of ANFIS in Civil Engineering- A Critical Review

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Abstract – This paper presents a critical review on application of Adaptive Neuro-Fuzzy Inference system (ANFIS) in Civil Engineering. The use of an adaptive neuro-fuzzy inference system (ANFIS) has received encouraging responses over the last decade in various research areas. In Civil Engineering nowadays widely uses such as CFST coloums, self compacting concrete. The ultimate compressive load of concrete-filled steel tubular (CFST) structural members is recognized as one of the most important engineering parameters for the design of such composite structures. ANFIS was applied to simulate the response of the model footing subjected to vertical centered and eccentric loads. The results of their study encourage the use of ANFIS in supporting the optimization of model testing program.

Key Words: Adaptive Neuro-Fuzzy Inference system (ANFIS), Compressive strength of concrete, Road Embankment, Structural damage identification, Bond Strength of Steel Reinforcement, Self-Compacting Concrete, Risk management, Railway station; overcrowding risk

1.INTRODUCTION

The ANFIS model has the advantage of having both numerical and linguistic knowledge. ANFIS also uses the ANN's ability to classify data and identify patterns. Compared to the ANN, the ANFIS model is more transparent to the user and causes less memorization errors. The adaptive neuro-fuzzy inference system (ANFIS) first proposed by Jang in 1993 [1], is one of the instances of neuro-fuzzy frameworks in which a fuzzy framework is carried out in the structure of adaptive organizations. ANFIS develops an information yield planning put together both with respect to human information (as fuzzy assuming standards) and on produced input-yield information sets by utilizing a mixture squares gauges. Perusers are alluded to References (Jang, 1993; Mashrei, 2010) on the ANFIS [2] . After produced input-yield via preparing, the ANFIS can be utilized to perceive information that is like any of the models displayed during the preparation stage .The adaptive neuro-fuzzy inference system has been utilized in the space of structural designing to tackle numerous issues Abdulkadir, 2006 [3]; Akbulut, 2004 [4]; Fonseca 2007[5]; Tesfamariam[6] and Najjaran, 2007 [7] . Most of the problems solved in civil and structural engineering using ANFIS are prediction of behavior based on given experimental results that are used for training and testing data. The matter of modeling is to solve a problem by predicting which is obtained by mapping a set of variables in input space to a set of response variables in output space through a model, conventionally a mathematical model is used. However, the conventional modeling of the underlying systems often tends to become quite intractable and very difficult. Recently an alternative approach to modeling has emerged under the rubric of soft computing with neural network and fuzzy logic as its main constituents. The development of these models, however requires a set of data. Fortunately, for many problems of civil engineering such data are available.

1.1 Concept of ANFIS

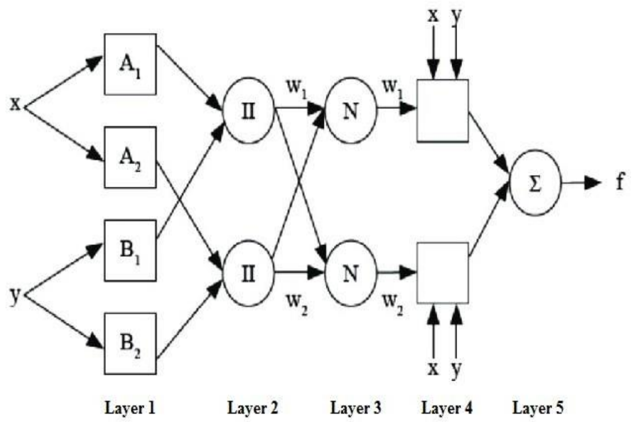

Fig: ANFIS Structure

The ANFIS system consists of five network layers that explain multi-layered neural networks (NN) and have separate purposes for each layer, which consists of multiple nodes represented by squares or circles and have distinct functions for each layer. The circle symbol symbolizes a non-adaptive node whose value is fixed, while the box sign denotes an adaptive node whose value can change with learning. The following are the functions and equations for each layer:

Layer 1: Fuzzification Layer

The function is to generate membership degrees. This layer is called the input layer. The nodes of this layer will be connected to the fuzzy membership values

$O_{1,i} = \mu_{Ai}(x)$ for i=1,2 and

$O_{1,i} = \mu_{Bi}(y)$ for i=3,4 (1)

X and y are input node i.

Layer 2: Product Layer

Each output node represents the degree of firing strength for each fuzzy rule. This function can be extended if the premise has more than two fuzzy sets. The number of vertices in this layer shows the number of rules that are formed

$O_{2,i} = w_i = \mu_{Ai}(x)\mu_{Bi}(y)$, for i = 1,2 (2)

Layer 3:

Normalizes firing strength. The layer of each node in this layer is an adaptive node that displays the function of normalized firing strength, which is the ratio of the output of the node i in the previous layer to the entire output ofthe previous layer, with the form of the node function:

Layer 4: Defuzzification Layer

Calculate the output of the rule based on the consequent

Layer 5: The Total Output Layer

Calculates the ANFIS output signal by adding up all the incoming signals.

Adaptive neuro fuzzy inference system (ANFIS) is a fuzzy inference system implementation to adaptive networks for developing fuzzy rules with proper membership functions to have required inputs and outputs.The most common training type in adaptive ANFIS is hybrid.Least mean squares and back propagation are used in hybrid training.

A fuzzy inference system is composed of five functional blocks as follows ;

(i) Input parameters to input membership functions.
(ii) Input membership function to rules.
(iii) Rules to a set of output characteristics.
(iv) Output characteristics to output membership functions.
(v) The output membership function to a single-valued output, or a decision associated with the output.

In fuzzy logic systems, two types of inference are used: Mamdani [8] and Sugeno[9] .The Sugeno method is well-suited to mathematical analysis and works well with optimization and adaptive techniques.This method also works well with linear techniques and ensures the output surface's continuity According to the benefits listed above, ANFIS only supports the Sugeno method.As a result, a brief explanation of the Sugeno method is provided.

2. APPLICATION OF ANFIS

2.1 Prediction of Compressive Strength

The ANFIS has a wide range of applications in Civil engineering. Several research have used the ANFIS to model concrete strength. Furthermore, the ANFIS is utilised to forecast concrete compressive strength based on nondestructive tests. As a result, the methodologies suggested in this work are practicable and viable for use with the ANFIS model in concrete strength measuring. The ANFIS is a novel FIS structure that incorporates fuzzy logic and neural networks . The ANFIS addresses the drawbacks of ANNs and fuzzy logic. To alter the parameters and outputs, the back propagation algorithm and the least squares approach are combined. Fuzzy NNs are used in the ANFIS to achieve fuzzy control, fuzzy reasoning, and anti-fuzzification. To create an adaptive neural fuzzycontroller, the rules are extracted from the sample data. To change the fuzzy inference control rules, offline and online learning algorithms are used, allowing the system to become adaptable, self-organizing, and self-correcting. Kabir et al. [10] presented a simple mathematical model for predicting concrete compressive strength based on its 7-day strength. A rational polynomial-based equation is used in the model to relate various parameters to the age and strength of concrete. For brick aggregates, this model has been found to produce satisfactory results. Such mathematical models necessitate expert knowledge of concrete strength interaction as well as parameter adjustment through trials and field expertise, making strength determination a complex process. Supe and Gupta [11] conducted research to develop a predictive model for in situ calculation of concrete compressive strength; specifically, they performed rapid curing at 100°C to predict the 1-day compressive strength and then used it to predict the 28-day strength. Although this method is simple to implement on-site, even for inexperienced workers, its accuracy is not always acceptable. For predicting, Viviani et al. [12] used a maturity method. They led early-age misshapening checking of substantial examples utilizing extensometers, which are optical fiber-based twisting sensors, to compute equivalency focuses. These were therefore used to figure the initiation energy and development of cement at 12 hours, which was additionally aligned at 3 and 7 days. The activation energy was further used to determine the compressive strength of cement. It was uncovered that 72 hours are sufficient for gathering information and leading the strength assessment of cement up to a positive precision, rather than hanging tight for 28 days. Albeit this technique has potential it includes complex sensors and master information on the substantial age and interaction equations. To use such forecasting in the field, a procedure or a tool is required to reduce the application complexity for the development business.

Neshat et al. [13] utilized an ANFIS model and a fluffy master framework (FES) model to foster a substantial blend plan. They reasoned that the ANFIS model performs similarly well or even better than the FES model, despite the fact that it requires substantially less effortor subject expert is ethan that needed in the FES model, in which the if–else rules have to be manually input into the system by a specialist. Ghoddousi et al. [14] introduced a bunch of FES and ANFIS submodels for the mix design of concrete It was concluded that themodel successfully provides the quantities of the different parts for the blend configuration, guaranteeing most extreme packing density and minimum cement content for a given design strength. Sinha et al. [15] fostered an ANFIS-based model for anticipating the compressive strength of superior execution concrete (HPC). The model fuses seven information factors and one result variable. Subtractive grouping was utilized as the base FIS andhybrid algorithm for training. With an optimumset of FIS parameters, the model was found to accurately predictthe compressive strength, in this way making the ANFIS reasonable in any event, for concrete with various fixings, as on account of HPC, for which different models need exactness and straight forwardness. Likewise, the ANFIS has been utilized for some different issues in the field of structural designing, including mechanical properties [16,17], flexibility factor [18], and strain in cement footers [19,20].

2.2 ROAD EMBANKMENT

Road construction involves a lot of logging and landfill work. Landfill activities require a compression process to meet the desired performance requirements. The land compressed by re-cultivation is known as the embankment. Used when the vertical alignment of the road needs to be raised from the existing surface to meet construction standards to prevent road surface damage. Although its construction is the longest construction technology, there have always been major technical challenges in the design process. One of the challenges arises when it is built on soft soil. Soft ground has a high subsidence rate when exposed to stress [21]. Slope stability and subsidence are essential factors for embankment stability. This is supported by Al Homood and Tanash [22] who have identified these two factors in assessing the stability of earth dams. Recently, many researchers have reported a correlation between slope stability and subsidence and an assessment of slope stability. During the design phase, engineers typically need to use the limit equilibrium method (LEM) [23] or the finite element method (FEM) [24] to calculate dam stability. This is a perfectly combined formulation to solve the problems of subsidence and slope stability. They make various assumptions and theories about some parameters due to time constraints and costs. Therefore, their level of knowledge greatly affects the accuracy of predictions. This approach can lead to uncertainties in prediction accuracy compared to actual stability in the field. This problem can be solved by using the correct forecasting method and approach. The reaction to the utilization of man-made brainpower (AI) in different fields has been empowering since its presentation in 1956 [25]. This is on the grounds that its nonlinear forecast capacity is better contrasted with different models. A large portion of the AI techniques are neural network, fuzzy logic (FL), hereditary programming and cross breed approaches like fluffy hereditary frameworks and neuro fuzzy. Computer based intelligence center approach, for example, ANFIS is a computation model for taking care of mind boggling issues for direction. ANFIS is a blend of a fuzzy inference system (FIS) and counterfeit neural system. FIS is a standard based framework comprising of three applied parts, specifically rule base, information base and surmising framework. This mix is because of the upsides of FIS that can deal with phonetic articulations while the ANN can learn without anyone else [26]. Furthermore, it is a handling instrument utilized for complex issue displaying, where connections between factor models are obscure. It permits fluffy frameworks to concentrate on the boundaries by utilizing versatile back propagation calculation. FIS can be produced from MATLAB programming utilizing the FL tool compartment. Al-Mahasneh et al. [27] highlight the advantages and suitability of using ANFIS for model development. Among the benefits highlighted is the ANFIS model's ability to predict accurately when it involves a known and fully understood physical relationship. In addition to producing high prediction accuracy, it also offers reasonable advantages in terms of simplicity, adaptability, robustness and seeks to a good generalize [28]. The previous century has seen the fast improvement of ANFIS models in geotechnical designing for prescient purposes [29]. The primary reason for forecast is precise and valid outcomes [30]. Advanced fluffy MFs is one of the best dynamic methodologies [31]. While specialists regularly utilize exemplary methodologies like the back-propagation (BP) and the least-squares (LS) approaches, some recommend the advancement of learning calculations in their examinations. The customary technique is basic however by and by has numerous issues [32]. Among these issues are their intermingling to a neighborhood least and the speed increase rate that is delicate to the learning system. Thusly, the transformative calculation approach is accepted to have the option to tackle the issue and work on the exactness of forecast. In the course of recent years, forecasts utilizing the ANFIS approach have been generally effective in demonstrating identified with bank security expectations. It was first utilized in this field of study in 2002 to foresee post stage rockfill dams [33]. Nonetheless, the writing survey affirms that no particular review revealed ANFIS's utilization to anticipate the incline steadiness and settlement of street bank. The greater part of the current examinations are just done in few regions, with the inclination to zero in on soil properties identified with bank security. As well as sharing information on the construction and model of ANFIS, there are two primary goals of this review: (I) To sum up past investigations on the advancement of ANFIS model to foresee street bank steadiness, (ii) To give the requirement for additional examination the ANFIS approach for a more complete expectation of street dike security. Plus, this paper is driven by the need to consider advancement methods in ANFIS. The consequences of this exploration are relied upon to contribute thoughts and discoveries to this developing field by investigating the ANFIS approach in foreseeing the security of street dike.

2.3 Structural Damage Identification

The damage will change the stiffness and mass of a structure, which will change the measured dynamic response of the system, such as natural frequencies and mode shapes. Damage detection at an early stage is critical for preventing sudden and catastrophic collapses and failures of structural systems and can improve safety, reduce maintenance costs and increase structure serviceability. As a result, it is critical to keep an eye on structures for signs of damage.

Many methods have been developed for locating and identifying damage in civil structures. Visual inspections, which are the most commonly used methods for detecting structural damage, are frequently insufficient for evaluating the condition of structural systems, especially when the damage is not visible. As a result, it is critical to monitor structural performance when damage is invisible in order to ensure structural integrity.

In recent decades, adaptive neuro-fuzzy interface system (ANFIS) as powerful artificial intelligence (AI) technique are becoming very accepted to predict the extent and location of damage in structures. ANFIS provides a method for the fuzzy modelling procedure to obtain information about a data set in order to compute the membership function parameters that best allow the associated fuzzy inference system to track the given input/output data [34]. ANFIS is a great tradeoff between ANNs and fuzzy logic systems that has the potential to capture the benefits and principles of both techniques in a single framework. Several studies have used ANFIS based on dynamic characteristics for damage identification., for example, explored multiple damage diagnosis in cantilever beam and bending plate as two structural systems using adaptive neuro-fuzzy inference system (ANFIS) and natural frequencies of structures by Fellahin and Seedpod [35]. A relative drop in elasticity modulus in each element was used to model damage variables. The proposed methodology's computational benefits for accurately recognizing the losses were demonstrated by numerical results. The ANFIS was found to have a high level of accuracy in identifying the most possibly damaged parts.

Danilatos discusses the use of ANFIS for bridge structure damage identification[36]. Moving loads were used to excite a simulated bridge structure in this study. According to this study, a damage diagnostic algorithm based on ANFIS was developed, with significant accuracy and remarkable flexibility as the main benefits of this work. In comparison to ANNs and multiple regression analysis, ANFIS was more efficient in the evaluation process and performed substantially better. It is presented how ANFIS was used to anticipate the behavior of steel beam web panels subjected to focused loads by Fonseca et al. [37]. The ANFIS architecture in this study was composed of one neuro-fuzzy classification model to classify the beams based on their pertinence to a specific structural response and one patch load prediction neural network to use the pertinence established by the neuro-fuzzy classification model and finally determine the patch load resistance of the beam.

2.4 Bond Strength of Steel Reinforcement in Self-Compacting Concrete

In built up substantial designs, the bond strength between steel support and cement is just about as significant as the compressive strength of concrete and one of the fundamental variables influencing the conduct of built up substantial components, particularly when encountering breaks. The benefits of utilizing self-compacting concrete (SCC) are decreasing the hour of development and the quantity of livelihoods, lessening commotion that can upset the general climate, and expanding the thickness of solidified cement primary components, consequently influencing bond strength support in SCC. The crack width and deflection are strongly influenced by the bond stress distribution along with the reinforcement and the slip between the steel reinforcement and the surrounding concrete [38]. The bond strength among reinforcement and concrete is impacted by many elements, some of them are compressive strength of cement, measurement reinforcement and advancement length[39].

With the development of concrete technology during the 1980s, Japanese specialists presented self-compacting concrete (SCC) by creating a model that was very effective in 1988. Self-compacting concrete is an innovative concrete that does not need vibration for placing and compaction. It can how under its weight, completely cling formwork and achieving full compaction, even in the presence of congested reinforcement. The advantages of using SCC are reducing the time of construction and reducing noise that can disturb the surrounding environment, the number of employments and creasing the density of hard concrete structural elements, automatically affect bond strength reinforcement in self compacting concrete [40,41]. The advancement of delicate registering, particularly in man-made brainpower, permits PC machines to have the option to take care of issues like those done by people. Some of the artificial intelligence that has been applied in the field of civil engineering is artificial neural networks (ANN), fuzzy logic (FL), and a combination of ANN and FL called Adaptive Neuro-Fuzzy Inference System or ANFIS. Furthermore, Neshat et al.[42], Amana and Moline [43], Mohammadhassani et al. [44] were applied ANFIS and FL models to analyze a concrete design mix, predicting strength shear reinforced concrete beam and high deflection beam. Therefore by combining the ANN and FL methods, namely the Adaptive Neuro-Fuzzy Inference System or abbreviated as ANFIS method where the membership function and rules (IF-THEN) can be determined from input data automatically through the learning process, so this model is expected to reduce the weaknesses of each method so that the resulting predictions will be more accurate. In this manuscript, the

ANFIS method has been used for predicting the bond strength in SCC. For showing the performance of the ANFIS model, the level of accuracy-based correlation coefficient (R^2) and Root Mean Square Error (RMSE) were determined.

2.5 Overcrowding Level Risk Assessment in Railway Stations

In recent years, the global demand for railway transportation has continued to increase, and it is expected that the global railway usage will continue to increase, The rail line network plays a significant job (both monetarily and socially) in helping the reduction of urban trace congestion. It also accelerates the decarburization in cities, societies sand constructed conditions. To ensure the safe and secure operation of stations and capture the real-time risk status, it is imperative to consider a dynamic and smart method for managing risk factors in stations. In this research, a structure to foster a shrewd framework for overseeing hazard is recommended. The adaptive neuro-fuzzy inference system (ANFIS) is proposed as a powerful, intelligently selected model to improve risk management and manage uncertainties in risk variables. Traveler streams in rail route frameworks are filling drastically in numerous urban areas over the world with the quick improvement of rail travel. This rejects on stations that face colossal tension from traveler clog and the significant degree of congestion in busy times. The metro frameworks in Beijing and Shanghai give an everyday transport administration to in excess of 9,000,000 travelers, and measurements show that the yearly utilization has nearly multiplied from 2011 to 2015 [45,46]. In the UK, the quantity of rail traveler ventures has dramatically increased in the course of the most recent 20 years [47]. Additionally, by 2050, more than 75% of the total populace is relied upon to be living in urban communities. It is really important for regions worldwide to help residents' portability inside the metropolitan climate. The British rail network is probably going to help traveler km by half, as per the public authority targets set out in the Ten-Year Plan for Transport [48]. Moreover, in some parts of the world, railway infrastructure has been used extensively for carrying large volumes of goods and is now ageing; for example, in Europe, the network infrastructure was built 150 years ago[49].

Thus, the profoundly requesting and concentrated utilization of old frameworks expands the danger element and holds the business under tension from both society and government. Besides, obliging an expanding number of individuals on open transportation is a test, particularly during top driving hours when congestion makes amazingly significant degrees of inconvenience and dangerous train stations for travelers. It has been noticed that swarming expands dangers to the wellbeing or potentially security of those ejected [50]. The industry over's some solutions, such as discouraging peak-time travel by means off are differentiation. However, this had no observable eject on passengers' travel patterns[51]. Railway stations are a fundamental piece of rail line frameworks; they are where travelers start and end their venture. Moreover, some stations now over business offices to explorers. This features the intricacy of the whole framework, by which stations are dynamic frameworks that need to oblige thousands or millions of individuals showing up and leaving each second, while depending on foundation plan, functional cycles, and different elements. Dealing with the traveler how in stations is fundamental since stations are a significant part of the public transportation framework and draw in an enormous number of travelers. Expanding clog in stations produces many dangers to be managed[52] and stays a significant wellspring of grievances by travelers. A few functional cycles should be overseen continuously, establishing a unique climate. Administrators should screen, examine, make due, explore factors, and update plans dependent fair and square of anticipated risk. This empowers them to choose proper plans and methodologies for decreasing dangers to an adequate level [53]. As of late, many examinations have been led to evaluate traveler framework within railway offices by observing and demonstrating passerby bows ("swarm elements" models). In any case, the administration of railways stations requires reexamination considering new innovations [54]. In this review, we propose a technique for restricting congestion and further developing the administration interaction. Our model uses a adaptive neuro-fuzzy inference system (ANFIS) for the momentary forecast of hazard level connecting with congestion. The proposed technique is beneficial to the station plan and format, swarm the board, crisis arranging, course planning, and improvement of wellbeing and security in comparable environments, which reject emphatically on the business and raise administration fulfillment. Many models consider the all out number of travelers enter in gestation. However, overcrowding might happen just on one stage. In our review, we consider the quantity of travelers on a solitary stage that is dictated by the travelers in pausing and the how from the station to the stage through the lifts or different channels. Also, we expect that the postponement of one train can abet only one stage. The data took care of to the model can be caught from pictures in the station that incorporate the spatial and worldly reliance of the group.

3. CONCLUSIONS

This paper presents a brief overview of Adaptive Neuro-Fuzzy Inference system applications in Civil Engineering field. The technique known as Adaptive Neuro-Fuzzy Inference System (ANFIS) seems to be suited successfully to model complex problems where the relationship between the model variables is unknown In this mainly three steps are used fuzzification, inference system and defuzzification. But it has a lot of applications that has been discovered and are realized these days. We have discussed two application in this paper.

Focused on developing a mode for predicting the compressive strength of concrete using the ANFIS , The average percentage of error for 3-day compressive strength and for 28-day compressive strength can be calculated. The calculated error for 3-day compressive strength is varied with the calculated error for 28-day results.

Using the ANFIS application, researchers from various countries have successfully published research papers on road embankment stability. The importance of developing road embankment stability prediction models with ANFIS applications is examined in this paper.

One of the more interesting findings of this study is the small number of researchers who predict road embankment stability by combining settlement and slope stability.

Based on the discussion presented in this paper, it is possible to conclude that the evidence and findings of the study can contribute. As a result, the study's findings have important implications for future practice. This is due to the fact that the information and findings presented are useful to researchers, particularly in the field of road embankment stability using the ANFIS approach.

The objective of this study is the development and demonstration of the utility of ANFIS-based damage identification techniques for damage localization and severity prediction in I-beam structures using modal parameters The experimental modal analysis of this structure is performed in this study to obtain the dynamic parameters, which include the structure's first five natural frequencies and mode shapes.

As per the exploratory from a few past research as preparing and testing information and ANFIS model over, some end comment can be gotten as follow

- ANFIS model was made in this review, the gauss participation capacity of the FIS model for input information compressive strength (face), the width of steel reinforcement (db), and development of length (Ld) effectively to appraise the bond strength of steel support in self-compacting concrete (SCC).
- The bond strength between self-compacting concrete and steel reinforcement depending on parameters compressive strength (face), the diameter of steel reinforcement (db), and development of length (Ld).

The ANFIS model utilized in this review can learn and determine a limit for the danger level depending upon area and group norms from exact ongoing information.

Estimating the risk level is an crucial outcome of our prediction, unlike traditional prediction studies that headlights only on station-level or route-level forecasting (time series).

A dynamic risk management model for railway stations based on ANFIS that can deal with active risk data indices in real-time has been developed. In terms of its ability to predict risk in railway stations, the ANFIS is one of the most successful systems. The chosen model appears to be reliable for projecting risk and guiding decision making for dynamic risk management in relation to the danger of overcrowding in railway stations, and it represents a step toward smart future railway stations.

More data and training are expected to be fed into the ANFIS model as input, resulting in more accurate results. Finally, decision-makers can act based on real-time knowledge of the station's congestion risk levels, which must be maintained. This model promotes and improves safety in terms of overcrowding risks, as well as preventing outgrowth. Supervising the selected overcrowding signs (input variables) can prevent dangerous events in many hot spots throughout the station, including the platforms, ticket gates, and tunnels.

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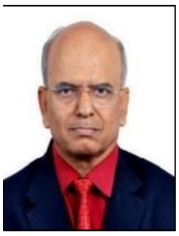

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