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SCOUR DEPTH PREDICTION ALONG THE SAND BED OF A 180° CHANNEL BEND USING GROUP METHOD OF DATA HANDLING (GMDH)

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ABSTRACT:

Calculating scour depth in open channel is very time taking and tedious job; especially if there is any curve or bend along the flow of the channel. Moreover, physical models are costly and not easily available for testing all hydraulic conditions. An accurate estimation of scour depth is also very difficult due to the complex behavior of flow in an erodible bed. In this study, Group Method of Data Handling (GMDH) was used to establish a relationship between the scour depths and bend angles. The bend angles of the channel (0° to 180°), and distances of various points along the width of the channel from inner side were used as input parameters while scour as the output parameter. To check the performance of the method, the standard statistical analyses such as standard Root Mean Square Error (RMSE), standard Mean Absolute Error (MAE), and correlation coefficient (R) were implemented. Results of GMDH show good estimation of scour in terms of both bend angles and distance along the width from inner side of the channel compared to the measured data from physical model.

***Key words:* Scour, regression analysis, forecasting, and GMDH.**

INTRODUCTION:

Scour is a phenomenon that occurs when the bed of an open channel is eroded by water flow and the force of water flow transports bed materials. The mechanism of this phenomenon is such that before destructive force of floods cause destruction to structure, erosion around the pier of bridge (By the water flow) and causing damage (Ettema R., *et al.* 2006).The flow pattern of scour is caused by localized structures. Depending on the structure of the material forming the substrate, flow and sediment transport conditions, vortex, which caused additional erosion force is applied to the substrate flow (Breusers & Raudkivi 1991). The additional erosive force increases the rate of sediment movement around the structure and flow down to the local context (Melville & Coleman 2000). Clash of the basiccauses the horseshoe vortex and flow separation are two main factors that causes scour (Melville & Chiwe 1999).

Conventional regression models are restricted to the conditions of laboratory as well as field studies, which often lack of validation for empirical equations in the scour depth prediction. Recently, different artificial intelligence approaches such as artificial neural network (ANN), adaptive neuro-fuzzy inference system (ANFIS), genetic programming (GP), linear genetic programming (LGP), gene-expression programming (GEP), evolutionary polynomial regression (EPR) were carried out to predict the local scour depth at the downstream of hydraulic structures (H.Md. Azmathullah*et al.* 2005, H.Md. Azmathullah*et al.*2008a and 2008b, A. Guven et al. 2008, A. Guven et al. 2012, D. Laucelli, and O. Giustolisi2011).

Amongst the various artificial intelligence methods, thegroup method of data handling (GMDH) network is knownfor its self-organizing approach to solve complex problems innon-linear systems (Hwang 2006; Amanifard *et al.* 2008).Recently, alternativeGMDH networks were utilized to predictscour around hydraulic structures. GMDH networks can be utilized to predict scour around hydraulic structures and to predict the scour depth around the bridge piers, abutments, and offshore structures (Najafzadeh and Barani 2011; Najafzadeh and Azamathulla 2012; Najafzadeh *et al.* 2012; Najafzadeh *et al.* 2013a, b, c, d; Najafzadeh and Barani 2013). Application of GMDH networks produced relatively more accurate prediction than those using conventional regression-based equations and other soft computing tools. In fact, the main feature of the GMDH networks is to build analytical functions within feed forward network in form of quadratic polynomial whose weighting coefficients are obtained by regression (Kalantary *et al.* 2009). The GMDH networks provide prosperous applications in various field of sciences such as forecasting of mobile communication, explosive cutting process, tool life testing in gun drilling, constructing optimal educational test, control engineering, marketing, economics and engineering geology (Astakhov and Galitsky 2005; Hwang 2006; Witczak et al.. 2006; Amanifard *et al*. 2008; Srinivasan 2008; Jamali *et al*. 2009; Abdel-Aal and El-Alfy 2009; Mehrara *et al.* 2009; Kalantary *et al.* 2009).

GROUP METHOD OF DATA HANDLING

GMDH is a self-organizing methodology, which gradually constructs complex models based on the evaluation of performances on a set of multiple-input and single-output data pairs (Jamali *et al.* 2008). The accuracy of forecasted or predicted valuein modeling techniques used for forecasting constitutes the underlying argument in support of a particular method. The performance of the model obtained by several alternative methods can be checked using some of the standard statistical measures, Mean Error (ME), Mean Absolute Error (MAE), Mean Squared Error (MSE), Mean Percentage Error (MPE), and Mean Absolute Percentage Error (MAPE).

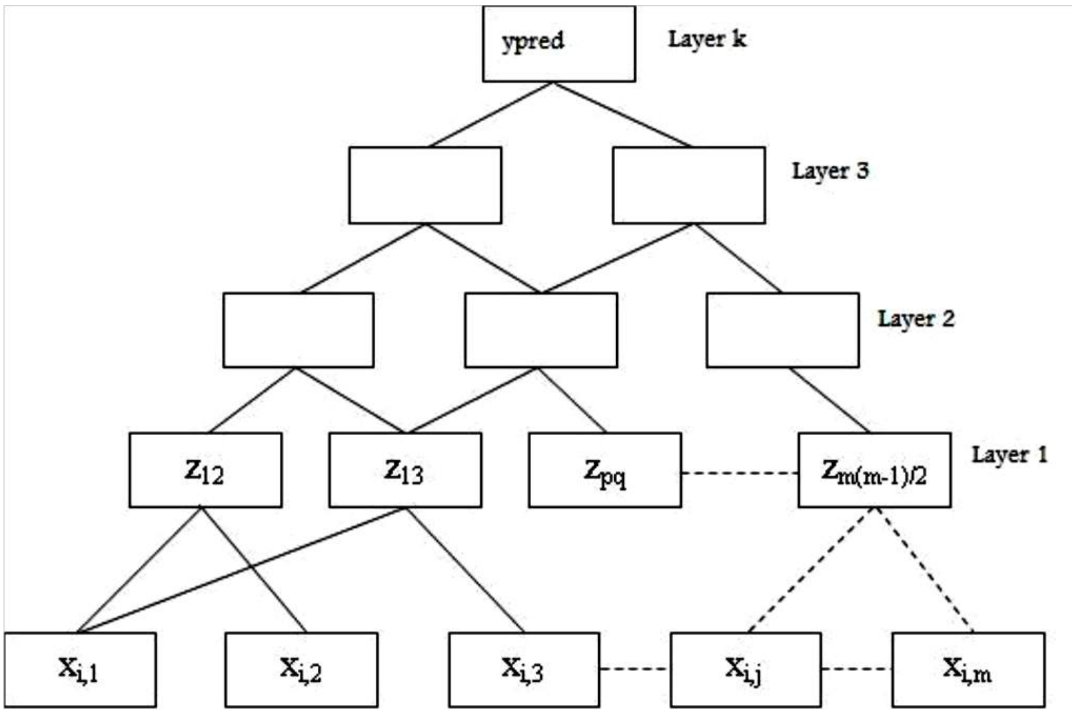

Figure 1: Self-organizing GMDH structure with m inputs and k layers

The GMDH algorithm is a set of neurons in which different pairs in each layer are connected through a quadratic polynomial and produce new neurons in the next layer. A typical structure of GMDH algorithm is depicted in Fig. 1. GMDH uses two sets of data, first set is training data and second set is control data, which are about 20% of the total data set.

A generic connection between inputs and outputs can be expressed by the series functions of Volterra which is the discrete analogous of the polynomial of Kolmogorov-Gabor (Nelles, O. 2001).

$$y = a + \sum b_i x_i + \sum\sum c_{ij} x_i x_j + \sum\sum\sum d_{ijk} x_i x_j x_k + \cdots + (1)$$

Where,

i=1, 2, 3 ……m;
j=1, 2, 3 ……m and;
k=1, 2, 3 ……m.
$x_{i,} x_{j,} x_k$: *inputs*
a, b, c : polynomial coefficients
y: output.

This full form of mathematical description can be represented by a system of partial quadratic polynomials consisting of only two variables (neurons) in the form of:

$$\hat{y} = G(x_i, x_j) = a + bx_i + cx_j + dx_i x_j + ex_i^2 + fx_j^2 \quad (2)$$

The main purpose is to make ŷ as much as possible close to actual output y.

The basic technique of GMDH learning algorithm is fundamentally consists of the following steps (A. G. Ivakhnenko and Y. U. Koppa. 1970):

1. From data sample including a dependent variable y and independent variables x_1, x_2,... ,x_m; Subdivide the data into two subsets: one for training and other for testing.
2. Feed the input data of m input variables and generate combination (w, 2) units from every two variable pairs at the first layer.
3. Estimate the weights of all units, 'a' to 'f' in equation (2) using training set.
4. Compute mean square error between y and predicted.
5. Sort out the unit by mean square error and eliminate bad units.
6. Set the prediction of units in the first layer to new input variables for the next layer, and build up a multi-layer structure by applying Steps (2) and (5).
7. When the mean square error become larger than that of the previous layer, stop adding layers and choose the minimum mean square error unit in the highest layer as the final model output.

GMDH works by building successive layers with complex links (or connections) that are the individual terms of a polynomial. The initial layer is simply the input layer. The first layer created is made by computing regressions of the input variables and then choosing the best ones. The second layer is created by computing regressions of the values in the first layer along with the input variables. This means that the algorithm essentially builds polynomials of polynomials (Srinivasan, D. 2008).

RESULTS AND DISCUSSION:

A quantitative examination of the fit of the predictive models was made by using error measurement indices, which are commonly used to evaluate forecasting models. The accuracy of the models was determined by using the mean absolute deviation (MAD), the mean absolute percentage error (MAPE), the MS error (MSE), and Correlation coefficient, R ; which can be defined as in the form of equations (1), (2), (3), and (4).

$$MAD = \frac{\sum_{i=1}^{n}|y_i - \hat{y}_i|}{n} \quad (1)$$

$$MAPE = \frac{\sum\left|\frac{y_i - \hat{y}_i}{y_i}\right|}{n} \times 100 \quad (2)$$

$$MSE = \frac{\sum_{i=1}^{n}|\hat{y}_i - y_i|^2}{n} \quad (3)$$

$$R = \frac{\sum_{i=1}^{n}[y_i - \bar{y}_{actual}][\hat{y}_i - \bar{y}_{predicted}]}{\sqrt{\sum_{i=1}^{n}[y_i - \bar{y}_{actual}]^2 . \sum_{i=1}^{n}[\hat{y}_i - \bar{y}_{predicted}]^2}} \quad (4)$$

Where,y_i equals the actual value, $\hat{y}_i$equals thepredicted value, and n equals the number of observations.

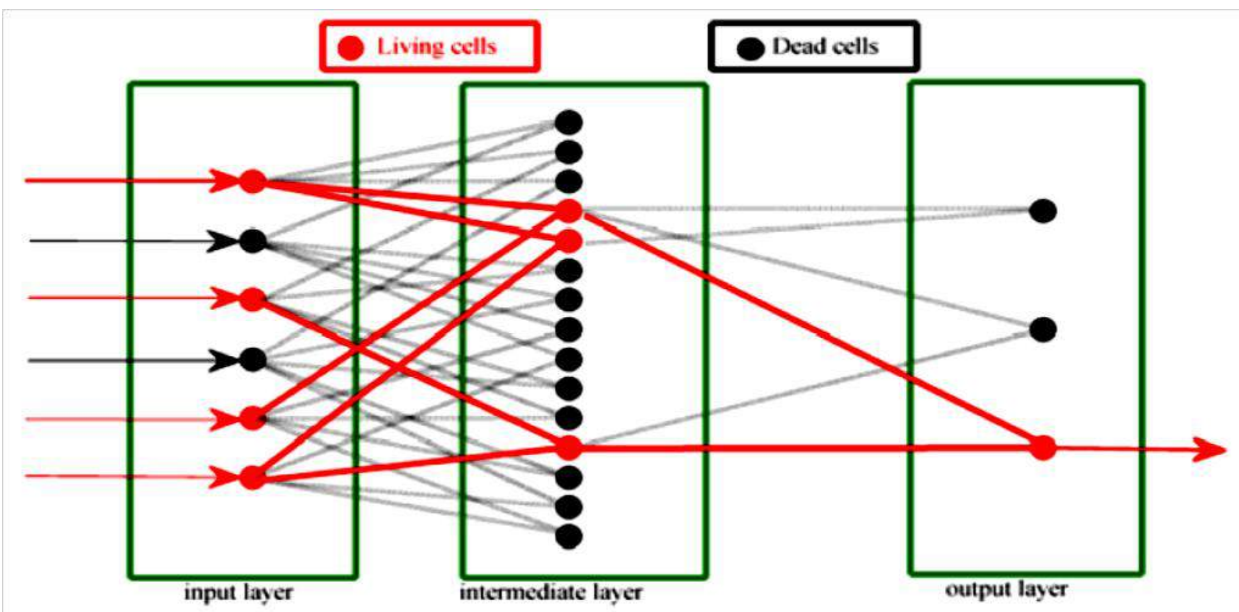

Figure. 2 The structure of the GMDH

The validation sets, which consisted of 29unpredictable input-output data lines during the training process, were used merely for validation to show the prediction ability of such evolved GMDH during the training process. After training the model (for 115 data set), the scour depth in at different angles of the channel bend were estimated for test data and the comparison was considered. The regression analysis was carried out by calculating the residuals from the experimental data and predicted data for training data set as shown in Figure 5. The results show that the correlation provided by GMDH analysis with root mean square error of the standard (0.83044 for model fit and 0.684772 for prediction),and mean absolute error standard (0.675048 for model fit and 0.581692 for predictions) is 0.97104 in case of model fit and 0.980822 for prediction. The details of the error and data fits to the model is shown in the Table 1.Comparison of observed, training and checking values as shown in Figure 3 with the predicted values describe good agreement following almost same path as shown in Figure 4.The scatter plot by taking one of the axes of the coordinate system as the other and axes measured as the estimated data plotted as depicted in Fig. 5. The distribution points are closer to the 45-degree line model shows better performance.

Table. 1: Model Accuracy

ACCURACY OF THE MODEL					
ABSOLUTE			**RANGE PERCENTAGE**		
Post processed Results	**Model Fit**	**Predictions**	**Post processed Results**	**Model Fit**	**Predictions**
Number of Observations	115	29	Number of Observations	115	29
Maximum Negative Error	-2.02651	-1.18222	Maximum Negative Error	-11.77%	-6.87%
Maximum Positive Error	1.68142	1.41087	Maximum Positive Error	9.76%	8.19%
Mean Absolute Error (MAE)	0.675048	0.581692	Normalized Mean Absolute Error (NMAE)	3.92%	3.38%
Root Mean Square Error (RMSE)	0.83044	0.684772	Normalized Root Mean Square Error (NRMSE)	4.82%	3.98%
Standard Deviation of Residuals	0.83044	0.651457	Standard Deviation of Residuals	4.82%	3.78%
Coefficient of Determination	0.94292	0.957835	Coefficient of Determination	0.94292	0.957835
Correlation	0.97104	0.980822	Correlation	0.97104	0.980822

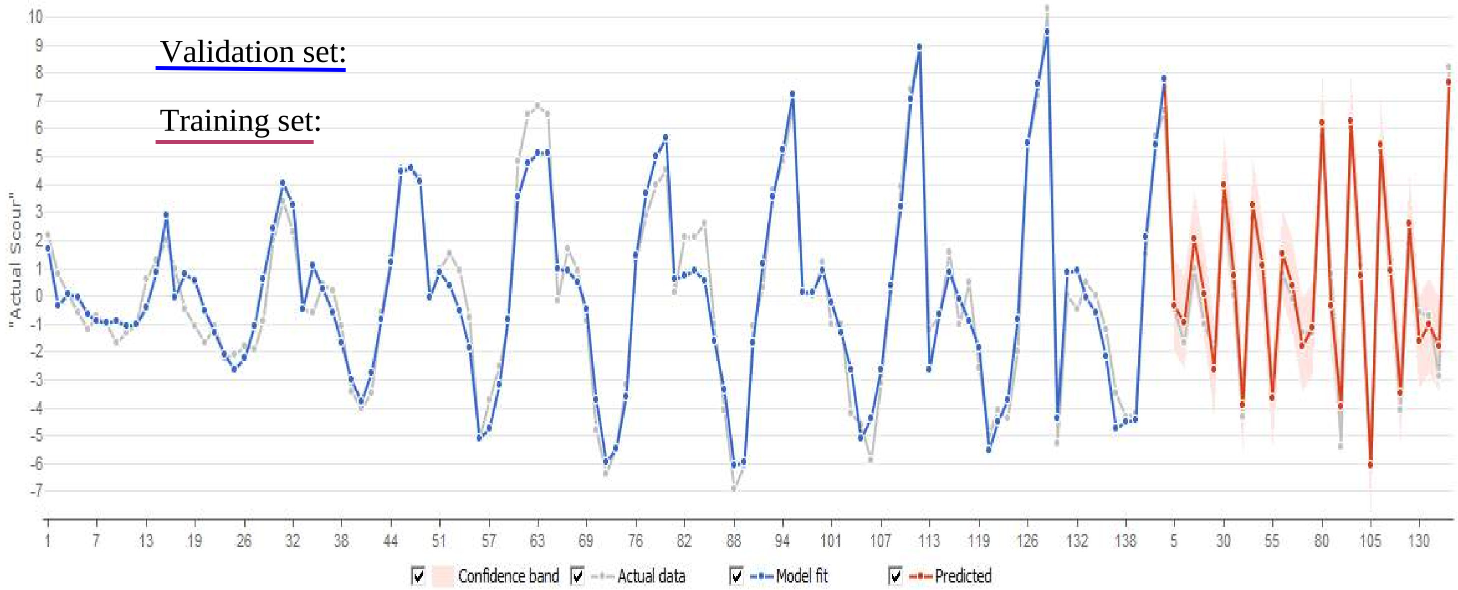

Fig 3: The comparison between observed value and training, checking value

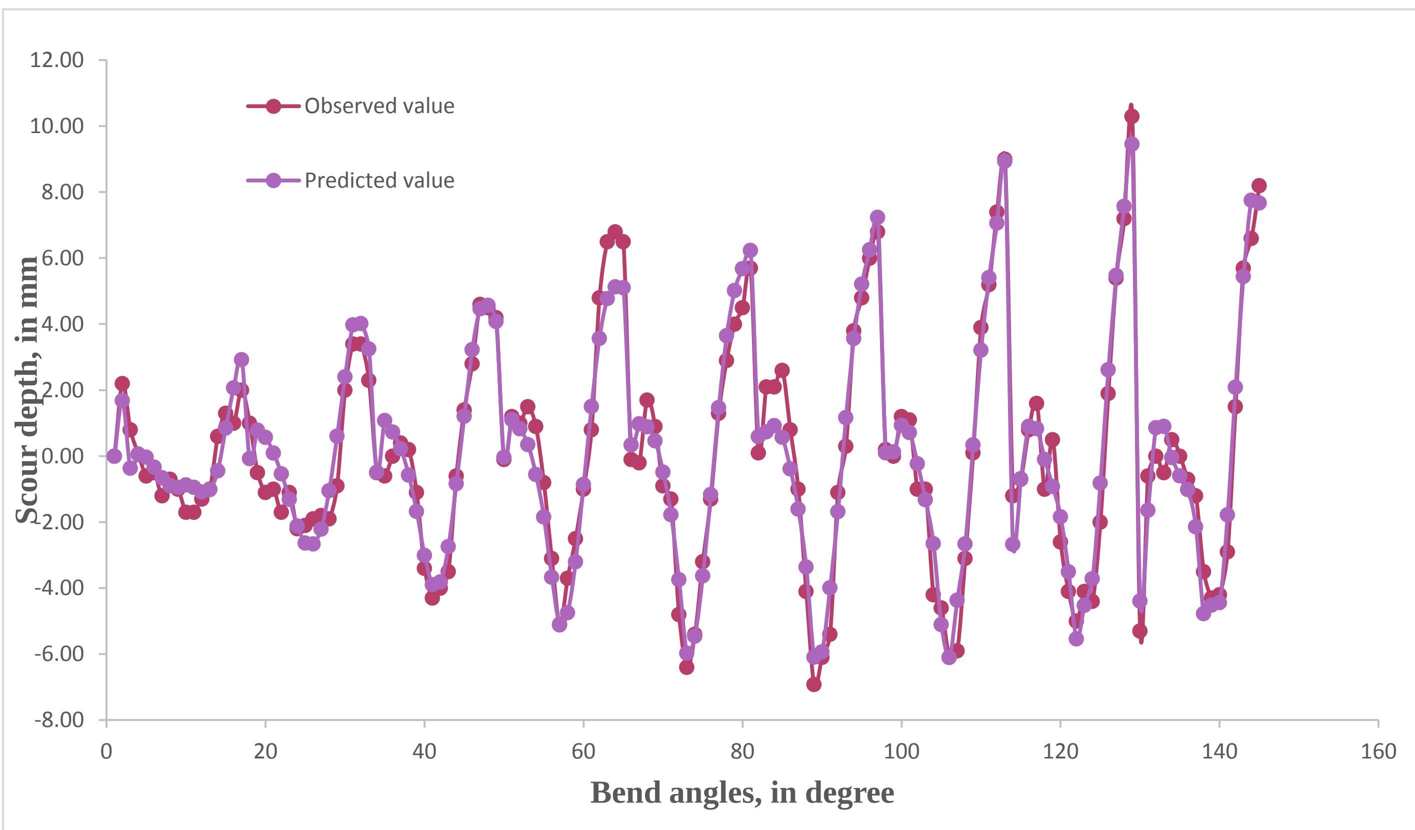

Figure 4: The comparison between observed value and prediction value

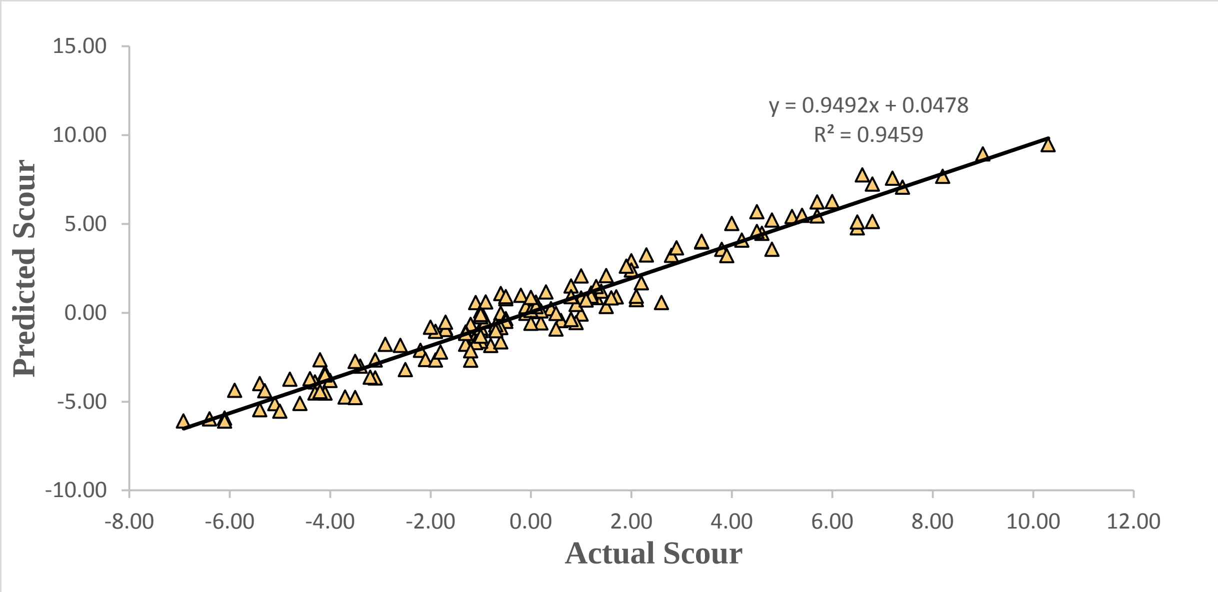

Figure 5: Scatter plot of predicted and actual scour.

CONCLUSIONS

This paper has presented scour depth forecasting in sandy bed of a 180° channel bend using GMDH. Main advantage of the GMDH algorithm in the current research is that it is essentially automatic and does not need to make complicated decision about the explicit form of approach for each particular case. With proper characteristic selection, it is obvious that GMDH is a more efficient and straightforward approach. The validation of results was tested by using 29 sets of data (validation sets) that were extracted from the database. The GMDH networks were trained with only 115 sets, and 29 sets were omitted. After the training process, the predicted values of neural networks were compared with those of actual values (the remaining 29 sets). Results (training and validation values) showed very good agreement with actual and predicted scour depth.

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