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Research Article

Durability Prediction Method of Concrete Soil Based on Deep Belief Network

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To truly reflect the durability characteristics of concrete subjected to multiple factors under complex environmental conditions, it is necessary to discuss the prediction of its durability. In response to the problem of durability prediction of traditional concrete structures, there is a low prediction accuracy, and the predicted time is long, and a concrete structural durability prediction method based on the deep belief network is proposed. The influencing factors of the concrete structural durability parameters are analyzed by two major categories of concrete material and external environmental conditions, and the transmission of chloride ions in the concrete structure is described. According to the disconnection of the steel bars, the durability of the concrete structure is started, and the determination is determined. The concrete structural antiflexural strength, using a deep belief network training concrete structural antiflexural strength judgment data, constructs a concrete structural durability predictive model and completes the durability prediction of the concrete structure based on the deep belief network. The proposed prediction method based on the deep belief network has a high prediction accuracy of 98% for the durability of concrete column structures. The simulation results show that the concrete structural durability's prediction accuracy is high and the prediction time is short. The prediction of concrete durability discussed here has important guiding significance for the improvement of concrete durability test methods and the improvement of concrete durability evaluation standards in China.

1. Introduction

The durability of concrete structures refers to the ability of concrete structures to maintain safety and applicability without massive reinforcement processing in normal design, construction, use, maintenance, etc. For a long time, the study of concrete durability has been lagging behind the study of concrete soil, and the emergence of durability in concrete structures has caused huge economic losses to countries. With the unprecedented increase in the construction of basic project construction, the durability of concrete structures is increasingly attached. Concrete is the most used building material in engineering and the most important structural material. The reinforced concrete structure has become the most widely used structure in the world [1, 2]. Although, with the proposal of the new structure and the emergence of new building materials, there will be many new structural forms in the future, but it is certain that the reinforced concrete structure is still one of the most commonly used structures in the new century. However, concrete structures gradually become old, damage, or even destroy under long-term natural environment and use, affecting structural functions and safety of structural materials, so structural durability is one of the important connotations of engineering structure [3]. About relevant statistics at home and abroad showed that economic losses caused by the durability of concrete structures, and as the environmental changes and functional requirements occur, durability problems were getting more and more prominent. In the past, the engineering community lacked sufficient understanding of the durability of concrete structures, and traditional design methods only focus on the safety and performance of structural use phases, and the awareness of durability design is not strong. It can be seen that it is very important to study the durability of concrete structures. First of all, concrete is the largest, large-purpose building material for its advantages, easy to form, high-temperature resistance, and high temperature. Due to the perfect combination with the steel bars, the reinforced concrete structure is also the most widely used structure. Most of the industrial and civil buildings, roads, bridges, and ports in the form of concrete structures have played an important role in the development of national economic development. In addition, if the durability problem is not treated in time, serious economic losses will be caused. According to reports, there is more than half of the American concrete bridge to corrode damage. A survey in 1998 in the United States shows that the repair cost of the concrete bridge accounts for 60% of all corrosion losses. Currently, the cost of developed countries such as Europe and the United States for engineering maintenance has taken more than half of the total cost of construction costs. The problem of durability in my country's concrete structures is also underestimated.

Gao [4] proposed a long-durability-based concrete life prediction method, which discusses the main life prediction model, including the rapid test method model, the mathematical model, and the probability analysis model of material performance deterioration, based on the previous research results discussed. The key issues need to be paid attention to during the prediction of concrete durability, and it has been prospected as follows: (1) comprehensively determine the measurement index system of concrete structure durability, and consider the correlation between the indexes; (2) consider the influence of different national standard test methods on durability results; (3) for indoor tests, establish a laboratory to simulate environmental changes manually; (4) the model-based life prediction is completed by determining the reliability type, and attention should be paid to improving the accuracy of parameter estimation. Liu et al. [5] proposed the prediction method of high-performance concrete and life prediction in the salt lake area. Taking Salt lake as an example, the climatic environment of salt lake is bad and will seriously affect the durability of concrete, proposing high-performance concrete durability and the life prediction method for salt lake area study. Under the preparation of related raw materials, the design concrete mix ratio improves the test piece loading device carries out the test of carbonized experiments and concrete life prediction experiments and calculation methods. The results show that high-strength high-performance concrete has antipressure, no corrosion, and long characteristics of life [6]. However, the concrete structural durability prediction accuracy of the concrete structure described above is low, and the prediction time is longer. At present, there are many research studies conducted on durability evaluation of concrete all around the world. The researchers mainly focus on two aspects: one is the determination of index weight of durability, and the other is the comprehensive evaluation method. However, since the deterioration mechanism of concrete is very complex, the cumulative damage is often a comprehensive result of multiple factors, such as the environmental effect, the properties of concrete with great uncertainties, and the limitation of detection technology. So far, the understanding of the durability of concrete is still in a preliminary stage.

For the above method, Section 1 proposes a predictive method of concrete structural durability based on the deep belief network and passes the simulation experiment to verify the prediction accuracy of the concrete structure of this paper. The prediction time is short, and the foundation is laid at the foundation for the construction. In Section 2, the durability prediction method of concrete structure is introduced in detail, and the related factors affecting its durability are analyzed in depth, and the durability prediction model of the concrete structure based on the deep trust network is proposed. In Section 3, simulation experiment analysis is carried out to verify the performance of the proposed durability prediction method in practical application, and finally, the experiment data are summarized and analyzed.

2. Concrete Structure Durability Prediction Method

2.1. Analysis of Factors Affecting Durability Parameters of Concrete Structure. There are many uncertain factors affecting durability, mainly including two categories: concrete material characteristics and external environmental conditions. The composition of concrete, such as hydrophilic ratio and cement type, directly affects the inner pore structure of the concrete (including the size of the diameter, the type, and the distribution state). The permeability of concrete after hardened is controlled by the porosity and pore structure of the capillary hole. The aggregate in concrete, especially the permeability of the crude aggregate, has more theoretical permeability. The more aggregates, the larger the area of the interface transition zone between the aggregate and the slurry, and since the porosity of the slurry is large, the permeability of the concrete is improved. Adding mineral binds, such as fly ash, slag, and silica ash, will greatly improve the structure of the hole and the interface transition zone so that the permeability of the concrete is greatly reduced [7]. In addition, construction and maintenance conditions directly affect the quality of concrete in the surface area, and the region is a key area affecting durability. If compared with outdoor natural conservation conditions, the surface of the concrete is relatively comparable, and the permeability is small. Due to maintenance, the structural cracks caused by external factors will also provide channels for chloride ions into the concrete. The form of the hole structure and crack can affect the transmission speed and range of chloride ions in concrete. In addition, as the exposure time is prolonged, the internal pore decreases in the concrete, the aperture decreases, and the channel of chloride ions entering concrete will also affect the transmission of chloride ions. Ambient temperature and humidity are important factors affecting the rust of steel. The concrete structure in the cold area will cause the protective layer to peel off and lose the protection of steel bars. The carbonization of the concrete also affects the chloride ion transmission. Carbonization means that CO_2 enters the concrete, reacting with $Ca(OH)_2$, reduces concrete alkalinity, and the passivation film of the reinforcing film begins in etching. When there is a chloride ion in the concrete, the carbonization speed is slightly lowered; while carbonization has greatly lowered the chloride binding ability, there is a certain degree of coupling [8].

2.2. Concrete Structural Durability Limit Status Estimation. According to the analysis result of the influencing factors of the durability parameters of concrete structures, the durability of the concrete structure is estimated.

The problem of concrete structures will have a durability problem, mainly because there is a pore inside, providing a channel to the harmful internal portion of the concrete. The specific transmission mechanism is related to the concrete dry and humidity and the environment. For concrete structures in the underwater saturation state, the main transmission mode of the chloride ion is diffusion, and its driving force is a concentration difference. When the concrete is in an unsaturated state, or when the saturation is uneven, the chloride ion enters the concrete, which is mainly capillary absorption, which is caused by the surface tension in the capillary. The capillary effect is the main transmission method of the chloride ion in the concrete structure in the tidal region and the amorphic region. In concrete structures, in the presence of a water head pressure in the wind, the chloride ion in the solution enters the concrete mainly due to the penetration effect caused by the pressure difference [9]. In addition, the transmission of chloride ions in the concrete structure also includes electrochemical migration, chemical adsorption, and a variety of ways coupled. For example, the lower portion of the rib is immersed in the concrete structure in the water, and there is a chloride ion penetration and diffusion, and the concrete structure of the amorphic region, while the chloride ion diffusion and capillary effects are present. In most cases, the transmission of chloride ions in the concrete structure has a variety of ways to work together [10].

In practice, the transmission of chloride ions in the concrete structure is described, and the transmission mode is generally simplified into diffusion transmission, and the diffusion process is used to describe the FICK second law:

$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial x^2}, \tag{1}$$

where C is the chloride ion concentration, D is the diffusion coefficient, t is exposed, and x is the distance from the surface of the member.

For the partial dimming equation of the formula (1), my country's "Concrete Structure Durability Design and Construction Guide" is based on the following assumptions:

(1) Concrete is a homogeneous half-unlimited space body
(2) Diffusion coefficient D is the value D_a
(3) It is assumed that there is no reduction in chemical reactions and physics during diffusion

Analytical solution of partial differential equations in a one-dimensional condition is as follows:

$$C(x,t) = C_0 + \left(C_{sa} - C_0\right)\left[1 - erf\left(\frac{x}{2\sqrt{D_a t}}\right)\right], \tag{2}$$

where $C(x,t)$ is the chloride concentration of chloride at x after t time; C_{sa} is the surface chloride ion concentration; erf is an error function.

After obtaining the transmission law of chloride ions in the concrete structure, the structure can be durable by the structure of the chloride ion concentration at the surface of the steel bar. For the durability problem of the diffusion transmission of chloride ions in the concrete, the durability of the concrete structure is estimated according to the disconnection of the steel bars, and the expression of the concrete structure is started, and its expression is as follows:

$$Z = g\left(C_{cr}, C_{sa}, x, D_a, n, t\right), \tag{3}$$

where C_{cr} represents a crowd of steel bars and begins the critical chloride concentration of rust; n represents the attenuation coefficient. When $Z > 0$, it is a reliable state of durability; when $Z = 0$ is durable, it is a durable limit state; when $Z < 0$, it is a durable failure state.

2.3. Concrete Structure Antiflexural Strength Judgment. Based on the above concrete structural durability limit, the concrete structural antiflexural strength is determined.

According to the multiple mechanical properties of the numerical simulation, the stabilization curve of concrete is obtained, and the stress-strain relational curve of the partial member of the concrete structure is analyzed, and the concrete is divided into strong restraints and weak restrains, and the overall antiflexural strength [11, 12]. The square cross section of the concrete is taken to reach the maximum value, the stress along the high direction of the concrete is ignored, the concrete cross section is divided as a constraint condition of the stress, and the concrete is divided into three regions, as shown in Figure 1.

The concrete is in the biaxial stress state$b$, and the pressure stress and the stress state of the concrete are manifested by acting on the concentration force of the square cross-section angle. The diameter of the concrete cross-sectional length is a, the diameter of the invalid constraint region is d, and the chamfered radius is R. Then, the calculation formula of the strong constrained area A_1 and the weak restraining area A_2 of the earth column is

$$\begin{cases} A_1 = \dfrac{2}{3}(b - 2R)^2, \\ \\ A_2 = b^2 - (4 - \pi)R^2 - \dfrac{\pi \cdot d^2}{4} - \dfrac{2}{3}(b - 2R)^2. \end{cases} \tag{4}$$

$$p = \frac{k_1 k_2 p'}{f}\left(\sqrt{\sigma_1^2 - \frac{3}{4}\sigma_2^2} - \frac{\sigma_2}{2}\right). \tag{5}$$

For the two regions, the radial pressure and loop are taken. Moreover, the lateral restraint stress is equal to the compressive stress and tensile stress, and the bonding effect will affect the bearing capacity of the axial body so that the

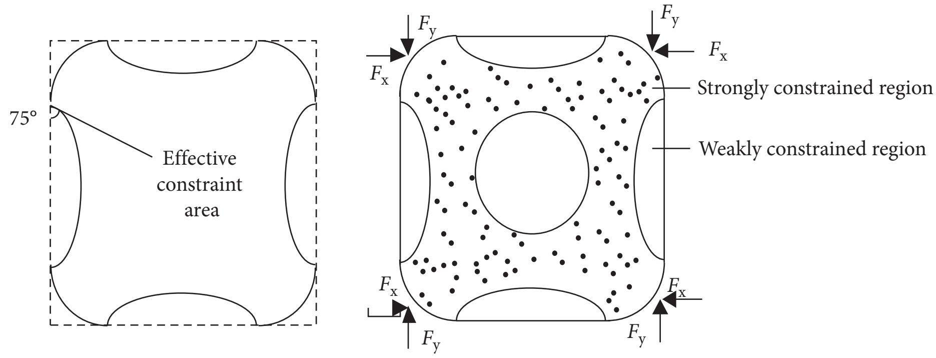

Figure 1: Concrete strip stress constraint area.

concrete is in three to the pressure state. Suppose that the uniform internal pressure on the outer layer of the concrete structure is p', the radial stress and circumferential stress are $\sigma_1\sigma_2$, respectively, the buckling strength of concrete without lateral pressure is f, the section shape factor is k_1, and the reduction factor of stress concentration at the corner is k_2. When the axial force reaches the critical value of concrete without crack compression, the calculation formula of the uniform external pressure p is as follows:

By substituting the relevant parameters of the two constraint regions into formula (5), the value of uniform external pressure can be determined, the uneven lateral restraint can be provided along the periphery of the concrete, the interference of the strength improvement coefficient in the compression state can be eliminated, the maximum constraint stress of the concrete core region can be determined, and then, the constraint stress of the two regions can be added [13–15]. Suppose that the external pressure in the strong constraint area is p_1 and that in the weak constraint area is p_2, then the calculation formula of the external pressure N under the compression state of concrete is as follows:

$$N = A_1 p_1 + A_2 p_2. \tag{6}$$

It is ensured that the compressive state of concrete is crack free so that the core concrete is in a passive restraint state. According to the stress-strain curve, the external pressure N is the buckling strength of concrete, so the buckling strength of concrete structure under compression can be obtained.

2.4. Prediction Model of Concrete Structure Durability Based on the Deep Belief Network. The deep belief network consists of several layers of neural networks, which are divided into the visible layer and the hidden layer. The visible layer is used to accept input, and the hidden layer is used to extract features. The deep belief network can be regarded as a deep neural network composed of a multilayer unsupervised restricted Boltzmann machine network and single-layer back propagation neural network, as shown in Figure 2.

Because the deep belief network has strong learning ability, this paper selects the deep belief network to train the concrete structure buckling strength judgment data, and according to the concrete structure buckling strength judgment data to learn the training results, this paper constructs the concrete structure durability prediction model.

The deep belief network is trained layer by layer, initializing the vectors in the initial unit, that is, mapping layer by layer from the first layer. The visible layer unit v of the deep belief network gets the hidden layer unit h through mapping, and the hidden layer unit h will be the visible layer unit of the next deep belief network, and the hidden layer unit will be obtained again through mapping, and so on until the training of multilayer deep belief network. In the training process, the weights of each layer are updated according to the correlation between the hidden layer and the visible layer. The network reconstruction error will be transferred from the first layer of the deep belief network to the second layer. Similarly, the reconstruction error of the second layer of the deep belief network will be transferred to the third layer, and so on until it spreads to the last layer of the deep belief network.

In the process of data learning and training of concrete structure buckling strength judgment, because the deep belief network is trained layer by layer, it cannot guarantee that the eigenvectors of the whole network layer are nonlinearly mapped to the best through training, and it can only ensure that the weights of each layer are nonlinearly mapped to the eigenvectors of the current layer to achieve the best. Therefore, the output data of the depth belief network are input into the BP neural network for the data learning training of the concrete structure buckling strength judgment, and the model parameter $\theta = (W, b, c)$ and the learning rate ε are obtained after the pretraining process. Then, the calculation formula of the error gradient σ_i of all visible layer elements v_i is as follows:

$$\sigma_i = Q_i(1 - Q_i)(e_i - Q_i), \tag{7}$$

where e_i is the desired output, and Q_i is the output unit of the visible layer.

The calculation formula of error gradient σ_j of all hidden layer elements h_i is as follows:

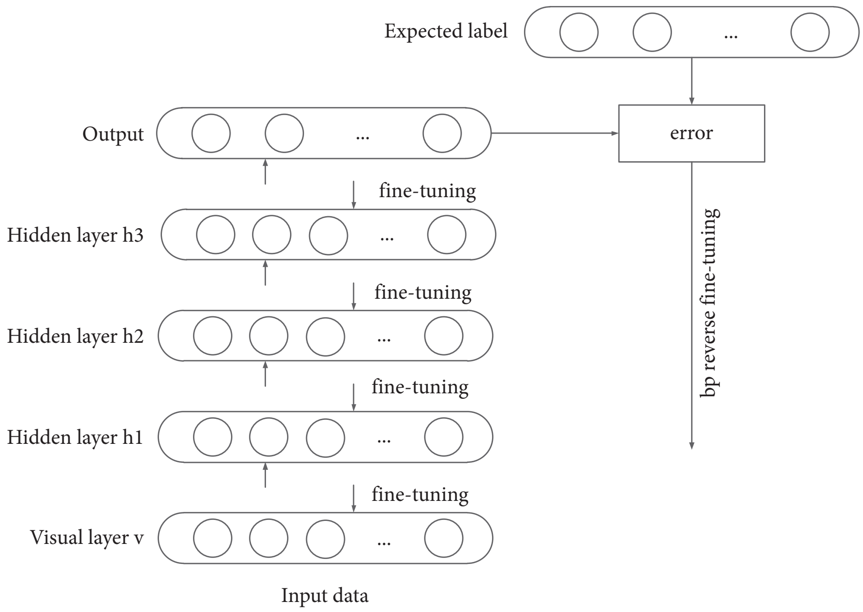

Figure 2: Deep belief network.

$$\sigma_j = Q_i(1 - Q_i)\sum_i \theta_{ij}\sigma_i h_i. \quad (8)$$

According to the error gradient value obtained above, the durability prediction model of concrete structure is constructed.where g_t is the gradient at time t and γ is the expected value coefficient.

$$E_t = \sigma_j + (1 - \gamma)g_t, \quad (9)$$

In the concrete structure durability prediction model, the training sample data are input to train the model, the test data are input into the trained model, and the predicted value of concrete structure durability is output in the output layer P.

$$P_P = E_t CH, \quad (10)$$

where C is the state of the deep belief network memory module and H is the output of the memory module.

3. Simulation Experiment Analysis

In order to verify the performance of the concrete structure durability prediction method based on the deep belief network in practical application, a simulation experiment is carried out.

Three groups of concrete column specimens, including a rectangle, a rectangle with straight ribs, and a stiffened rectangle, are selected, with 10 specimens in each group. The outer edge length is 150 mm, the column height is 500 mm, the inner pipe specification is 76 mm × 4 mm, and the chamfer radius is 20 mm. The concrete preparation steps are as follows: a template is made, the end of the specimen is marked relative to the two axial strain gauges, two U-shaped templates are crossed to form a side template so that the strain gauge is located on the compressive side of the specimen, concrete is then poured, and the other strain gauge is kept on the tensile side of the specimen. After concrete curing, the surface of the specimen is polished, and finally, FRP cloth is wrapped, and the specific specimen parameters are shown in Table 1.

The method of this paper, the method of literature [4], and the method of literature [5] are used to predict the structural durability of concrete column specimens, and the prediction accuracy of the three methods is compared. The comparison results are shown in Figure 3.

According to Figure 3, the prediction accuracy of concrete column structure durability of this method is up to 98%, while that of literature [4] and literature [5] is up to 78% and 30%. The prediction accuracy of concrete column structure durability of this method is higher than that of literature [4] and literature [5].

In order to further verify the effectiveness of this method, the prediction time of concrete column structure durability of this method, reference [4] method, and reference [5] method are compared and analyzed, and the comparison results are shown in Figure 4.

According to Figure 4, it can be seen that the prediction time of concrete column structure durability of the method in this paper is within 5 s, while the prediction time of concrete column structure durability of the method in literature [4] and literature [5] is within 30 s and 40 s. The prediction time of concrete column structure durability of this method is shorter than that of literature [4] and literature [5]. The prediction accuracy of the deep belief network model is largely affected by the amount of data in the model. The larger the amount of data, the better the prediction effect. Hence, the overall trend predicted here has good accuracy in tracking.

Table 1: Parameters of concrete column specimens.

Specimen number	Eccentricity (mm)	Cube strength (MPa)	Number of layers of externally wrapped FRP
1	0	54.9	2-layer circumferential FRP
2	0	53.9	2-layer circumferential FRP + 1-layer axial FRP
3	5	54.4	2-layer axial FRP + 2-layer circumferential FRP
4	5	57.1	3-layer axial FRP + 2-layer circumferential FRP
5	15	53.0	1-layer axial FRP + 2-layer circumferential FRP
6	15	52.1	1-layer axial FRP + 2-layer circumferential FRP
7	20	55.0	2-layer axial FRP + 2-layer circumferential FRP
8	20	50.6	3-layer axial FRP + 2-layer circumferential FRP
9	30	56.9	2-layer axial FRP + 2-layer circumferential FRP
10	30	52.6	1-layer axial FRP + 2-layer circumferential FRP

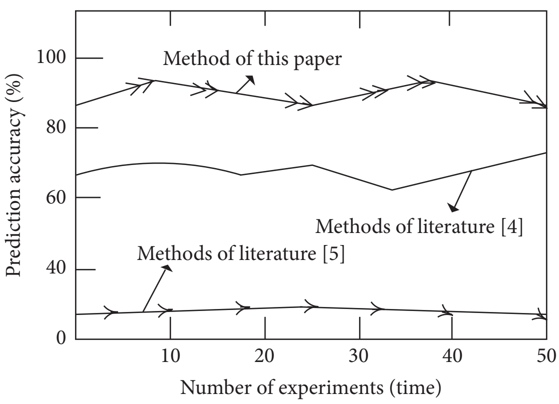

Figure 3: Comparison of prediction accuracy of structural durability of concrete column specimens.

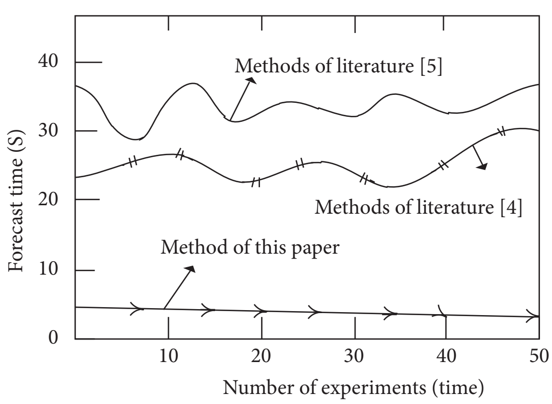

Figure 4: Comparison of prediction time for structural durability of concrete column specimens.

4. Conclusions

Concrete is the vertical load-bearing component of building structure, which generally exists in industrial, civil, bridge, and other projects. Due to the corrosion and cracking of the concrete, the buckling bearing capacity of the concrete column will be reduced or damaged, which will cause serious harm to the superstructure. Therefore, it is necessary to predict the durability of the concrete structure and carry out deeper research. There are many factors that lead to the deterioration of the durability of concrete structures, including the aging of materials and the structural damage caused by human or environmental factors. The accumulation of these factors will lead to the deterioration of structural durability and the decline of bearing capacity, and it is an irreversible process. Among the factors that affect the durability of concrete, reinforcement corrosion caused by chloride ion pollution is the main culprit, accounting for more than 30% of all factors. Once the steel bar begins to rust, there will be a series of problems, such as the diameter of the steel bar gradually decreases, the adhesive force between the steel bar and the concrete decreases, the volume expansion of the corrosion products leads to the cracking of the cover concrete along the steel bar, and the spalling of the cover, which eventually leads to the decline of the structural bearing capacity until the loss. Therefore, this paper proposes a concrete structure durability prediction method based on the deep belief network, and the effectiveness of this method is verified by simulation experiments. The fuzzy comprehensive evaluation method can effectively deal with fuzzy and uncertain information in the durability evaluation of concrete structures, but the index system adopted by different scholars is different, which is not involved here. In subsequent studies, the fuzzy comprehensive evaluation method can be further applied to the evaluation in other actual scenarios.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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