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철근콘크리트 프리캐스트 대형판 접합부의 설계 및 해석

Design and Analysis on The Connections of RC Precast Large Panel

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요 약

본 연구에서는 철근콘크리트 프리캐스트 대형판의 접합부 설계방법 및 해석방법에 대해서 연구를 수행 하였다. 접합부의 설계방법은 수평접합부와 수직접합부의 구조적 거동에 대한 안정성 및 일체성을 확보하기 위한 설계법을 제시 하였고, 접합부의 해석은 강체스프링 모델에 의한 탄소성해석을 수행 하였다.

Abstract

Precast large panel structures have various connection system such as the horizontal slab-to-wall connection, the vertical wall to wall connection, horizontal slab-to-slab connection, etc. Horizontal connection is connected by vertical tie bars, and vertical joint is connected loop bars and shear keys. The basic function is equalized deformations on later forces and the entire wall panel assembly acts as monolithic actions. Under lateral load some slip occurs in almost vertical connections. The shape and detail of precast connections are very important to the monolithic behavior of overall structures. The paper is a study on the design method and new elasto-plastic analysis of the connections by rigid-bodies spring model.

키워드 : 프리캐스트 대형 판넬, 탄소성 해석, 강체스프링 모델

Keywords : Precast large panel, Elasto-plastic analysis, Rigid-bodies spring model

1. Introduction

The design method must be satisfied the proper design and construction of precast large panel buildings. The precast building design must be covered specified loading, required strength and minimum requirements for integrity, effective reinforcing detail, proper wall and floor systems, handling and election consideration, seismic and wind loads. Precast large panel structures have various connection system such as the horizontal slab-to-wall connection, the vertical wall to wall connection, horizontal slab-to-slab connection, etc. Horizontal connection is connected by vertical tie bars, and vertical joint is connected loop bars and shear keys. The basic function of precast large panel connections are equalized deformations on later forces and the entire wall panel assembly acts as monolithic actions.

In this study, it will be proposed the design method of overall precast structures and elasto-plastic analytical method of precast large panel connections by the rigid-bodies spring model.

2. The System of Precast Large Panel Structures

2.1 Stability

Precast large panel structures should be arranged

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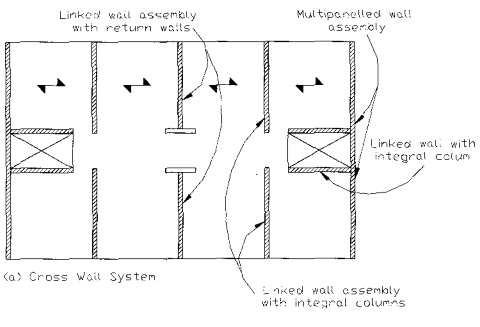
with bracing panels that provide lateral load resistance in two perpendicular vertical planes. Bracing panel should be continuous the full height of the structures to ensure stability. When discontinuity occurs, reinforcing should be provide to ensure transfer of strength across the discontinuity.

Floor components of precast large panel building should be assembled in such a way as to create a rigid diaphragm in the plane of each floor. To ensure diaphragm action, continuous grouted keys or mechanical connections with sufficient stiffness should be employed between longitudinal sides of precast floor and roof elements in combination with the horizontal ties. Continuity of the peripheral ties is necessary to develop diaphragm actions.

2.2 Structural Plan Form and Wall System

To enhance to overall structural integrity of the structure, the following should be considered when developing the structural plan form. When vertical stabilizing walls or cores are required to resist lateral loads perpendicular to the main load-bearing walls, at least two such load resisting elements should be provides within the plan of the building as shown in <Fig. 1>. This is necessary to ensure that the structural stability of the building as a whole is not lost in the event that one is damaged by some abnormal incident.

Tensile continuity should be provide between element within a wall assembly. This continuity can be effectively achieved by providing a system of transverse and vertical reinforcing ties across and within the joints. Care should be taken to ensure that all ties are anchored. Where splices are required, special attention should be given to detail to ensure continuity.



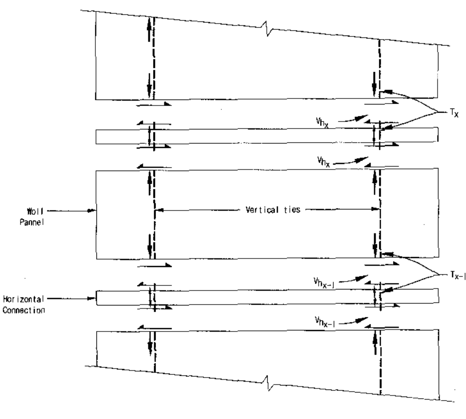
〈Fig. 1〉 Assembles of wall structural system

2.3 Transverse Ties

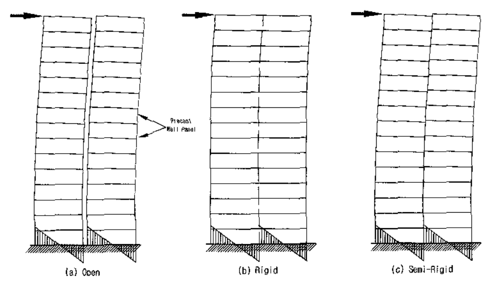
Transverse ties should be located at or within the horizontal joints between all stories of every primary load-bearing wall assembly. This tie should be continuos the full length of the wall panel. Each transverse tie should extend continuously across the bay between peripheral ties or transverse ties.

2.4 Vertical Ties

Vertical ties should be provided within each primary and secondary wall assembly. The ties should be continuous the full height of the assembly and all should lie within the peripheral tie system.



〈Fig. 2〉 Forces resisted by vertical ties



〈Fig. 3〉 Mechanical behavior of vertical joint

3. The Mechanical Behavior of Precast Large Panel Connections

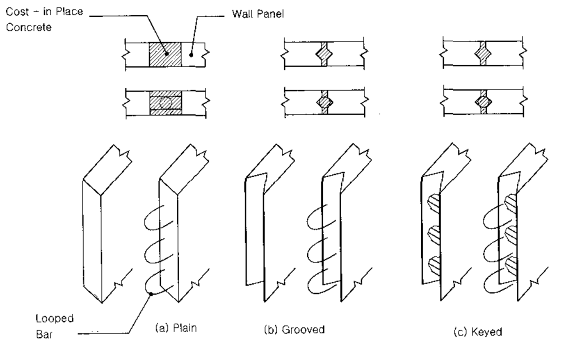
3.1 Mechanical Behavior of Vertical Connection

The basic function of a vertical connection is to equalize deformation between adjoining stacks of wall panels through in-plane shear. When wall assemblies are subjected to lateral forces, shear, compressive and tensile stresses will also be transferred through the joint. Vertical connection details significantly affect behavior of walls in response to lateral loads. With regard to this behavior, the connection is classified as open, rigid, or semi-rigid.

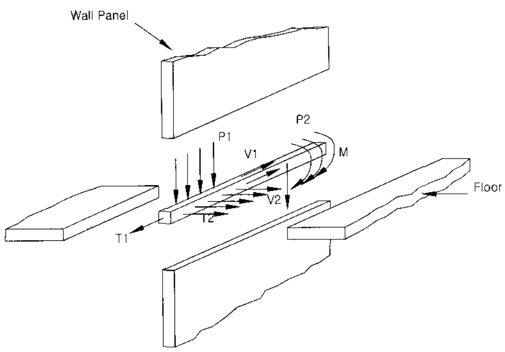
With an open connection, no shear force is transmitted from one stack of panels to another. A rigid connection provides full interaction between stack of wall panels. Under lateral force, the entire wall panel assembly acts a monolithic cantilever. In the semi-rigid joint, under lateral load some slip occurs in almost all vertical connection. The shear rigidity of semi-rigid connection is less than the rigidity of the stacks of adjoining wall panels. As a result, the shear stress transferred across the connection is accompanied by slip between the adjoining wall panels. Slip can be minimized in either connection with proper attention given to details. For the purpose of analysis, a small amount of slip is insignificant. However, when significant slip can occur, it must be considered in the design and detailing of structures.

3.2 Mechanical Behavior of Horizontal Connection

Horizontal connection between wall elements function mainly have in transmitting compression between wall panels. However, they should be designed to resist all the forces and moments implicit in the assumptions made in analyzing the structure as a whole and in designing the individual members to be joined.



〈Fig. 4〉 Types of vertical wall-to-wall connections



〈Fig. 5〉 Mechanical behavior of horizontal joint

3.3 Performance Criteria of Connection

Under normal loading conditions, interior and exterior horizontal wall-to-floor connections should be designed to satisfactorily transmit the primary and secondary forces.

Vertical connections act primarily to transfer vertical shear forces between adjacent wall element. These forces are due to unequal wall deformations or composite action under lateral loading. In design, considerations should be given to eccentricities induced from joint geometry and to the influence of joint rigidity on the analysis and design of composite wall assemblies.

3.4 Internal Forces of Connections

The minimum requirement for integrity can satisfy additional capacity for P1 and V1 in certain instance. These additional requirement should be considered in the design of all interior and exterior wall-to-floor connections. Under normal loadings, vertical wall-to-wall connections should be designed to satisfactorily transmit the primary and secondary forces designed below.

P1=Vertical load
P2=Vertical load from floor or roof panels
V1=Horizontal shear in the plane of the floor due to lateral load
V2=Horizontal shear in the plane of the floor due to diaphragm load
T1=Horizontal trust in the plane of the floor
T2=Horizontal trust in the plane of the floor
M=Moment from floor continuity

3.5 Other Forces

Precast unit should resist, without permanent damage, all forces induced by handling, storage and transport. The minimum age of handling and transporting should be related to concrete strength, type of unit and other relevant factors. The position of lifting and supporting points, method of lifting and type of equipment and transport to be used should be as specified. Points of support during storage should be chosen to prevent unacceptable permanent distortion of the unit. During transport, the following additional factors require consideration, distortion of transporting vehicle.

4. Elasto-Plastic Analysis of Precast Large Panel By Rigid-Bodies Spring Model

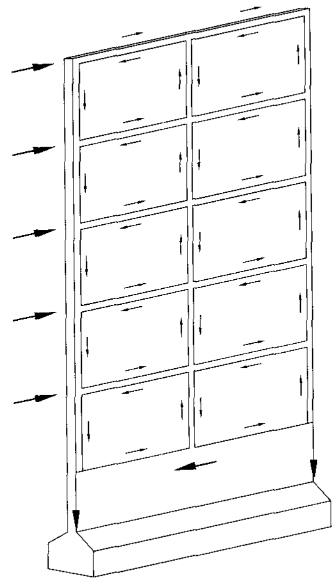
4.1 Introduction of Rigid Mod-Bodies Springeling

In order to overcome difficulties encountered in the finite non-linear analysis, it is proposed a family of new discrete elements which are called a rigid bodies-spring model. In the rigid bodies-spring model, each collapsed part or piece of structures at the limiting state of loading is assumed to behave like rigid bodies. When structures or solids reach their ultimate state of loading they may be yielded, collapsed and crushed into pieces. At the limiting state each part or piece of the structures may move like a rigid body. And the relative slip movement of adjacent pieces occurs along the contact surfaces. In the initiation and growth of cracks, the discontinuous displacement occurs on the divided surfaces.

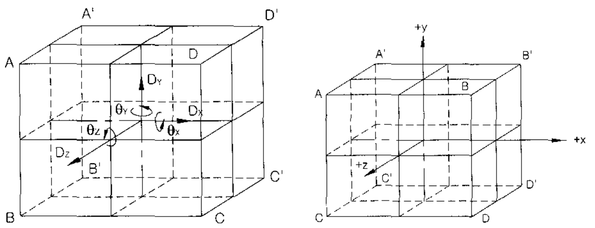
In rigid element method, when the continuum is analyzed by the numerical discrete technique, the discrete elements are assumed to rigid bodies, and these elements are interconnected with the spring system which transmits the internal forces. The behavior of overall structures is estimated by that of rigid elements and the spring system. In this paper, it is proposed how this rigid element spring model can be applied to the elasto-plastic analysis of precast large panel structures. Some numerical results of elasto-plastic analysis and experimental results such as the curve of load-displacement and the yielding and fracturing pattern of precast large panel structures under horizontal load are shown.

4.2. New Precast Panel Element

Rigid element spring model of precast large panel structures composed of the division of rectangular rigid element with spring system as shown in <Fig. 6>. The precast panel element has 3 movable rigid displacements and 3 rotational rigid displacements at the center of element as shown in <Fig. 7>. Supposing that the rotational displacements are very small, the equation of the displacement in a point around the element affected by 6 center rigid displacements in the center of the element can be obtained.



〈Fig. 6〉 Precast large panel structures



〈Fig. 7〉 Precast panel element

4.3 Analytical Procedure by Rigid-Bodies Spring Model

In the analytical method by the new discrete model of structures, at first the equation of the relations between shell element and spring must be determined by considering the behavior of spring and center rigid displacement. This is called adaptation equation of element. The adaptation equation represents displacements by the rigid behavior in a point around the element affected by center rigid displacements in the center of the element. And the total stiffness equation is obtained by the principle of virtual work. Substituting boundary condition into the total stiffness equation, the relative displacement and internal forces of springs are obtained. The axial forces, normal forces, shear forces and bending moments on contact surfaces of element are obtained by the internal forces of springs.

The spring-α is connected with a point 'i' of element-M and 'j' of element-N, and the adaptation equation of spring-α of shell element can be expressed as

$$\{u_i\}_M = [A_i]_M \{D\}_M \tag{1}$$

$$\{u_j\}_N = [A_j]_N \{D\}_N \tag{2}$$

The equation that transforms the displacements u, v and w into the displacement d_A, d_S, d_N corresponding to each side of the element is derived as

$$\begin{Bmatrix} d_A \\ d_S \\ d_N \end{Bmatrix} = \begin{bmatrix} \cos\eta & \sin\eta & 0 \\ -\sin\eta & \cos\eta & 0 \\ 0 & 0 & \xi \end{bmatrix} \begin{Bmatrix} u \\ v \\ w \end{Bmatrix} \tag{3}$$

$$\{d\} = \{T^1\}\{u\} \tag{4}$$

In Eq.(3), η and ξ are changed according to the direction of each element side. From Eqs.(1), (2) and (4), the following formulae are derived.

$$\{d_i\}_M = [T_i^1]_M [A_i]_M [D]_M \tag{5}$$

$$\{d_j\}_N = [T_j^1]_N [A_j]_N [D]_N \tag{6}$$

By consideration of the transformation matrix $[T^2]$ between the global coordinate system for overall structure and the local coordinate system for each element, Eqs.(5) and (6) can be rewritten as

$$\{d_i\}_M = [T_i^1]_M [A_i]_M [T^2]_M [I]_N [D] \tag{7}$$

$$\{d_j\}_N = [T_j^1]_N [A_j]_N [T^2]_N [I]_N [D] \tag{8}$$

By combination of Eqs. (7) and (8), the relative displacement of spring-α is given as

$$\{d\}_\alpha = \{[T_i]_M [A_i]_M [T^2]_M [I]_M + [T_j]_N [A_j]_N [T^2]_N [I]_N\}\{D\} \tag{9}$$

In Eq.(9), $[I]$ is the unit matrix of each element, and $\{D\}$ is the expanded column vector of rigid displacements in the global coordinate system, The internal forces of spring-α is written as

$$\begin{Bmatrix} f_A \\ f_S \\ f_N \end{Bmatrix}_\alpha = \begin{bmatrix} k_A & 0 & 0 \\ 0 & k_S & 0 \\ 0 & 0 & k_N \end{bmatrix} \begin{Bmatrix} d_A \\ d_S \\ d_N \end{Bmatrix}_\alpha \quad (10)$$

$$\{f\} = \{k\}_\alpha \{d\}_\alpha \quad (11)$$

Substitution of Eq.(9) into Eq.(11) yields the internal forces of spring-α as follows:

$$\{f\}_\alpha = \Big\{ [K]_\alpha [T_i^{\,1}]_M [A_i]_M [T^2]_M [I]_M + [K]_\alpha [T_j^{\,1}]_N [A_j]_N [T^2]_N [I]_N \Big\} \{D\} \quad (12)$$

The application of the principle of virtual work gives the following relationship, where n is the number of springs.

$$\delta\{D\}^T\{F\} = \sum_{\alpha=1}^{n} \delta\{d\}_\alpha{}^T\{f\}_\alpha \quad (13)$$

Substitution of Eqs.(9) and (12) into Eq.(13) yields the total stiffness equation of structures as follows.

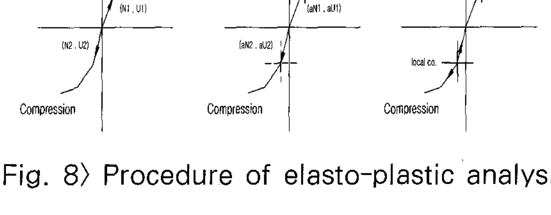
$$\{F\} = \{K\}\{D\} \quad (14)$$

$$\begin{aligned} \{K\} = \sum_{\alpha=1}^{n} \Big\{ & [I]_M{}^T [T^2]_M{}^T [A_i]_M{}^T [T_i^{\,1}]_M{}^T [K]_\alpha [T_i^{\,1}]_M [A_i]_M [T^2]_M [I]_M \\ & + [I]_M{}^T [T^2]_M{}^T [A_i]_M{}^T [T_i^{\,1}]_M{}^T [K]_\alpha [T_j^{\,1}]_N [A_j]_N [T^2]_N [I]_N \\ & + [I]_N{}^T [T^2]_N{}^T [A_j]_N{}^T [T_j^{\,1}]_N{}^T [K]_\alpha [T_i^{\,1}]_M [A_i]_M [T^2]_M [I]_M \\ & + [I]_N{}^T [T^2]_N{}^T [A_j]_N{}^T [T_j^{\,1}]_N{}^T [K]_\alpha [T_j^{\,1}]_N [A_j]_N [T^2]_N [I]_N \Big\} \end{aligned} \quad (15)$$

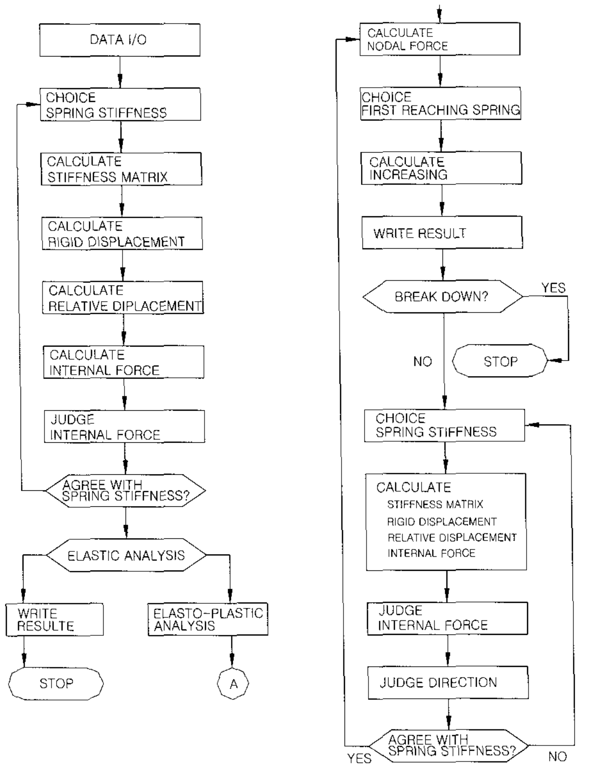
4.4. Elasto-Plastic Analysis Procedure of Structures

In the rigid element spring model, structures are composed of a set of finite rigid elements. The internal forces are distributed over the spring system which connects the rigid elements. The connection springs have the characteristics of elasto-plastic material. When the internal force is backward in plastic range(the 2nd grade and the 3rd grade), the elastic grade(the 1st grade)is selected. The essential information required in the analysis of structures by the rigid element spring model is to obtain the spring stiffness with the mechanical properties of continuum.

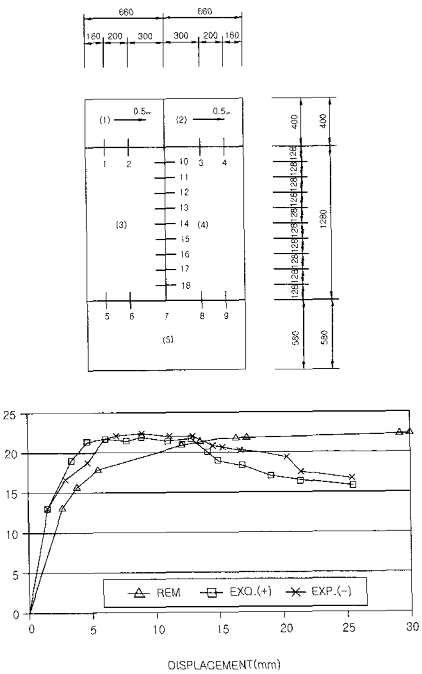
The spring stiffness can be obtained by the experimental testing in general, and differs according to the constitutive material of structures. Because the reinforced concrete structures differs the tensional stiffness from the compressive stiffness, it is needed to distinguish between the stress-strain relationship of tension and that of compression. Because it is previously not decided to choose the compressive stiffness and tensional stiffness for the axial force of spring, the tensional stiffness is used in calculated at first. If the sign of the relative displacement in results is negative, it is converted to the compressive stiffness. And this procedure is repeated until the sign of spring stiffness is consistent with that of the relative displacement. From the results for the unit load in elastic range, one spring which can be reached to a node, first of all, is chosen, and the incremental load of the spring necessary to reach to the node is calculated. Stage 3 : After taking the origin of the local coordinate system at the point where the internal force of each spring for the unit load is multiplied by the incremental load, each spring stiffness is again selected. These procedures of structures are continuously iterated from stage 1 to stage 3 up to the fracture of structures as shown in <Fig. 8> and <Fig. 9>.



〈Fig. 8〉 Procedure of elasto-plastic analysis



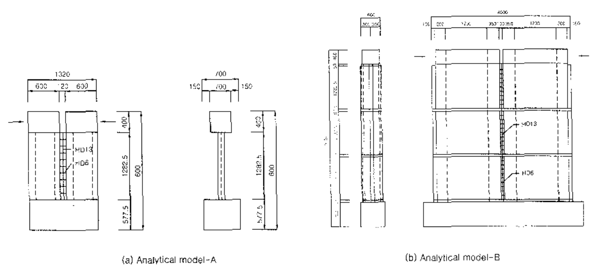
〈Fig. 9〉 Flow chart of elasto-plastic analysis



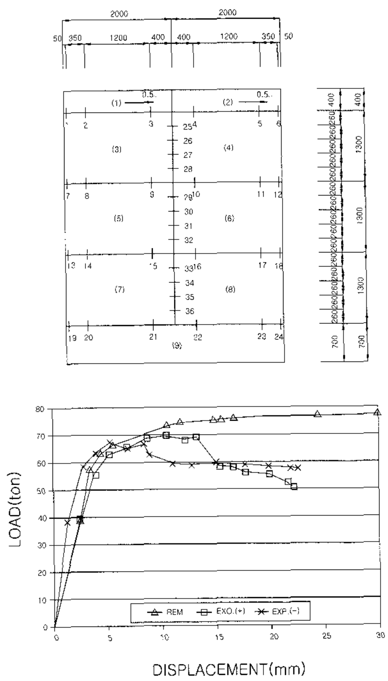
〈Fig. 11〉 Elasto-plastic analysis of precast panels under horizontal load

4.5. Elasto-Plastic Analysis of Precast Large Panel Structures

An analytical model is precast large panel structures under horizontal load as shown in <Fig. 10> · <Fig. 11> and <Fig. 12> show the analytic and experimental result of load-deflection curve.



〈Fig. 10〉 Model of precast panels under horizontal load



〈Fig.12〉 Elasto-plastic analysis of precast panels under horizontal load

5. Conclusion

In the design of precast large panel structures, It is proposed the design philosophy of establishing structural integrity, effects of abnormal loading are considered using explicit recommendations for system and member continuity and ductility. The design recommendations are provide to form a basic for adequate structural safety and serviceability under any loading condition or effect. This study related to the basic design concepts design of large panel concrete building. And it is proposed how the rigid element spring model can be applied to the elasto-plastic analysis of precast large panel structures. The procedures of elasto-plastic analysis on the discrete analysis of structure is proposed. The the curve of load-displacement and experimental result and numerical results are shown. Analyzing the results of some numerical analysis of precast structures, the present author believes that the effect of slip movement, the initiation and growth of cracks and the characteristics of displacement discontinuity can be easily treated by the spring system which is assumed to be the elasto-plastic material taking tri-linear model.

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