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Precast and Prestressed Concrete for the Future Construction of Sudurpaschim

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Abstract

Concrete is the second most consumed material in the earth after water. While concrete has been used for more than 2000 years, widespread use of precast elements has emerged as the latest concrete technology for quality of construction. Precast concrete follows modular construction approach which is sometimes classified as one of the top ten construction innovations. The widespread application of precast concrete was augmented by the invention of prestressed concrete as a revolutionary technology in concrete. This study provides an overview of the use of precast and prestressed concrete technology in Nepal. It highlights the benefits of concrete for national economy by utilizing domestic resources and in realizing sustainable development through durable construction. Recent applications of precast and prestressed concrete in Nepal are highlighted, with examples from various structures including building, river training, slope stability, hydropower and tunnel projects. The challenging aspects of precast and prestressed construction are also illustrated with examples. Research and development of precast and prestressed concrete products in Nepal are highlighted by presenting the initiatives from experimental studies and academic research. Even though Nepal is in the early stage of application of precast and prestressed concrete technology, the initial applications indicate a huge potential and great benefits of application of such products for the faster, cost-effective and durable construction in various parts of Nepal.

Keywords: Buildings, bridges, hydropower, precast concrete, prestressed concrete

Introduction

Concrete is the most widespread construction material in the world. Structures older than 2000 years have been traced to be constructed with concrete. Concrete is a highly customizable product with a scope to engineer its properties. For instance, concrete can be produced with compressive strength lower than 1 MPa in case of light weight concrete (Chaipanich & Chindaprasirt, 2015) to higher than 800 MPa in case of ultra-high performance concrete (Richard & Cheyrezy, 1994). Concrete is workable fluid to loose solid when cast and becomes solid mass after hardening. Owing to this feature, concrete can be prepared in virtually any shape with the help of appropriate formwork. Concrete can be either cast at the place where it is going to be used (cast in place or cast in situ concrete) or cast at a different place from where it is being used (precast concrete). Precast concrete has certain advantages over the cast in situ concrete. For example, precast concrete components may be suitable for work spaces that are narrow, occupied for services, or covered by water, mud or loose soil. Owing to the controlled work space and environment, precast concrete is generally superior in quality compared to the cast in situ concrete. Precast concrete can create the effect of additional work fronts at a site because the work can be split into two parallel work fronts, one cast-in-situ and another precast. This can substantially reduce the construction duration of a project that is often accompanied by savings in the project cost. Moreover, a reduced duration often translates into an additional return of the project by serving its intended purpose earlier. For repetitive nature of work, precast concrete is usually economical because the same formwork can be repeatedly used and the production can be mechanized. Modular construction technology is sometimes hailed as one of the top ten buildings innovations for civil engineers (Jackson, 2015). Owing to such advantages, precast concrete elements have been increasingly used all over the world. Precast concrete has been helpful to realize the fast pace of infrastructure construction. It is said that the level of infrastructure development that took 200 years for the UK took 30 years for Japan and less than 20 years for China. Even though the weightage of contribution is difficult to ascertain, precast concrete also contributed for this accelerated development. A study estimates that global precast concrete market size was 107.83 billion US dollars in 2018 and is expected to increase at an annual growth rate of 5.7% to reach 168.17 billion US dollars by 2026 (Reports and Data, 2019). In 2018, the Asia Pacific region occupied its largest market share of 31% largely owing to the demand of precast concrete in infrastructure construction in emerging economies, including China and India (Reports and Data, 2019). Precast concrete is therefore an essential means for realizing the aspiration of developing countries in expediting infrastructure construction.

Concrete technology has been an active research and development field for several years. Many new products and processes have evolved. One such revolutionary innovation of the 20th century was the prestressing of concrete. Prestressing can prevent the cracking of concrete, thus, enhance the durability of concrete. While concrete is weak in tension, prestressing brings the concrete under compression, thus, enhancing the strength of a concrete section. Moreover, prestressing can significantly reduce the deflection of beams and slabs and allows for larger spans compared to the reinforced concrete. By utilizing the efficient use of concrete owing to prestressing, concrete sections could be made slimmer and thus economical. The widespread application of precast concrete was augmented by the invention of prestressed concrete.

While precast and prestressed concrete technologies are widespread in developed countries, they can be regarded as in the early stage of adoption in Nepal, particularly for the case for the structural components. Nepal has aspirations to expedite infrastructure construction and to attain sustainable development goals (SDGs) by 2030 (NPC, 2020). Accordingly, some large scale projects are being implemented. Precast and prestressed concrete structures are being introduced in buildings, tunnels, roads, bridges, electrification, and hydropower structures. Lately, some precast concrete production companies have emerged in the construction industry. Experimental research on precast prestressed concrete has been initiated in graduate level of engineering education in Nepal. This paper reviews the historical use of precast and prestressed concrete technology in Nepal, illustrates the current state of use through some example projects and global contexts, and discusses the prospects of precast and prestressed concrete applications in the development of Nepal, with some emphasis on Sudurpaschim province.

Methodology

While precast concrete is used to produce both structural and non-structural members, this paper emphasizes the use of structural components. Structural elements include large structures such as bridge girders and hollow core slabs, and minor structures such as compound walls. Not all the precast components are prestressed. Likewise, not all the prestressed components are precast. For the prestressed components, prestressing could be either through pre-tensioning such as in hollow core panels or through post-tensioning such as in bridge girders (cast-in-situ). While precast and prestressed technologies were used in some structures in the past, hardly any documents are available on this aspect. Therefore, this paper aimed to document the historical use of precast concrete in Nepal. However, this is not an exclusive review of the past account of work in the field of precast and prestressed concrete in Nepal. The history and present status of the use of precast and prestressed concrete is based on literature review, personal communication and on the author's experience in a precast prestressed concrete company in Nepal. Future prospects are discussed based on the knowledge and experience of working in the construction industry in Nepal and abroad. In line with the theme of the conference, this paper either explicitly mentions the context of Sudurpaschim Province or presents the context of Nepal that is relevant also for this Province.

Results and Discussion

Application of Precast and Prestressed Concrete in Nepal

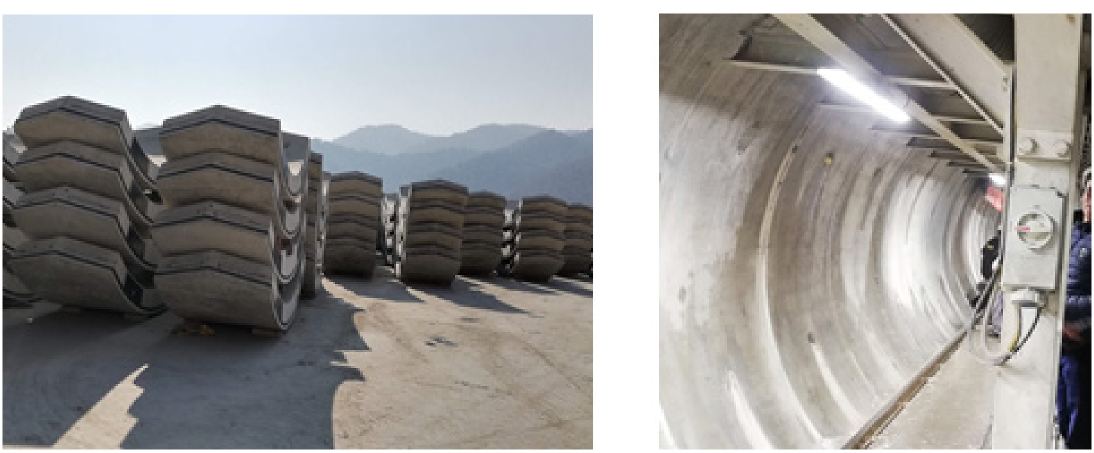
Hydropower and Irrigation Sector

TBM Segments

Excavation of tunnel has two dominant methods, namely, drill and blast method (D&B or DBM) and tunnel boring machine (TBM) method. DBM has been used in several hydropower projects in Nepal and is being used for the excavation of Nagdhunga Road Tunnel. TBM, on the other hand, was used for the first time in Bheri-Babai Diversion Multipurpose Project. Successively, TBM is being used in Sunkoshi-Marin Diversion Multipurpose Project. TBM excavation is often accompanied by precast concrete segments which form an interlocking circular ring to line the tunnel. Figure 1 shows the stack of precast segments of Bheri-Babai project on the left and their use inside the tunnel on the right. Concrete segments for TBM construction should be of superior quality with tight tolerance in size and shape and with specified compressive strength of 50 MPa or more. Precast construction technology allows to produce concrete segments of superior quality consistently. For instance, the average 28-day concrete compressive strength of the segments in Bheri-Babai project exceeded 65 MPa (personal communication with the Engineer involved).

Figure 1

Precast concrete segments in Bheri-Babai Diversion Multipurpose Project



Surge Shaft Cover

Hydropower construction involves large and complex structures with difficult site conditions. Precast concrete can be advantageous in some of such critical situations. One such application of precast and prestressed concrete involved the construction of the top cover of the surge shaft of Midim Hydropower Project, Lamjung. The surge shaft was approximately 23 m deep with an internal diameter of 6 m. Its top was exposed to sky at a level slightly above the ground and besides a road. Therefore, a sturdy cover was needed but construction using cast-in-situ concrete or structural steel was deemed difficult. Precast and prestressed concrete panels of 120 mm thickness, along with two ISMB 250 steel sections welded with a flange plate, were chosen as the cover structure as shown in Figure 2.

Figure 2

Surge shaft of Midim Hydropower Plant on the left and its cover made of precast prestressed hollow core panels on the right

Prestressed Bridges

Bridges often employ post-tensioning method of prestressing of bridge girders. Highway construction in Nepal began with technical and financial support from friend countries. Systematic official records of the historical use of prestressing in Nepali highway bridges are not available. Jhumsa bridge in Palpa, constructed along the Siddartha Highway in 1971, is considered as the first bridge in Nepal employing prestressing technology (Jaishi, 2022). Many other bridges have been constructed in Nepal using prestressing technology but official records are scarce. The 420 m long bridge over Narayani River near Narayangadh was constructed in 1980s. It consists of 14 spans of 30 m length and employs prestressing technology (Jaishi, 2022). Rapti bridge along Mahendra Highway was constructed by using prestressing technology in 1986. Mahakali to Kohalpur sector of Mahendra Highway (most part lying on Sudurpaschim) is reported to have 21 prestressed concrete bridges that were constructed during 1990s to 2000s (Jaishi, 2022). However, involvement of Nepali engineers in the design and construction of prestressed bridge in Nepal was negligible until the construction of the Kothiyaghat bridge in 2010s. This bridge is 1015 m long and is the longest motorable bridge in Nepal till now. This bridge, along with the Karnali bridge at Chisapani, connects Sudurpaschim Province with the rest of Nepal. After construction of this bridge, Department of Roads entered into a new era of bridge construction by extensively utilizing the advantages of prestressing technology and employing template designs (Jaishi, 2022).

One of the most significant advantages of prestressing in bridges is the possibility to increase the span length. While the span length of a typical reinforced concrete girder bridge is limited to 20 to 25 m, span length of 40 to 45 m has been commonly adopted for bridges with prestressing. Prestressed concrete bridge has become one of the popular bridge types in Nepal. These days, a number of bridges along highways, feeder roads and district roads can be seen as being constructed using the prestressing technology. However, this construction technology has brought some new challenges to the designers and contractors. A bridge over Badighad Khola near Wamitaksar, Gulmi collapsed twice in two years in a row because of the poor formwork propping that encountered dry season floods both times. Thimura bridge over Trishuli River connecting Chitwan and Tanahun districts (Figure 4) also suffered a similar fate. Out of the four spans, three spans were designed as prestressed concrete girders and the third span from the right was designed as a steel truss bridge. Span# 1 and #2 from the right were collapsed after casting of concrete and before prestressing in April 2021 (Adhikari et al., 2022) [Span #2 appears to be reconstructed as shown in Figure 4 taken in October 2022]. Contractors that were habitual of relatively shorter spans could not adequately plan for relatively longer spans of the prestressed bridges. The traditional way of formwork construction was inadequate. Some challenges of prestressed concrete bridge construction were highlighted in the failure investigation of Thimura bridge (Adhikari et al., 2022). These incidents should be seriously analyzed and discussed as great lessons to Nepali engineers for safe design and construction of prestressed bridges in future.

Figure 3

1015 m long Kothiyaghat Bridge over Karnali River

Figure 4

Under-construction Thimura Bridge near Devghat area

Road

Road infrastructure uses the most varieties of precast concrete products. Dividers, road side barrier blocks, barrier poles, kerb stones and paver blocks are most commonly used precast concrete elements. An environmental friendly grass paver (Figure 5) allows percolation of rainwater, prevents water patches and puddles along the footpath, and enhances the aesthetics by permitting growth of green grass through its holes. Precast roadside drains are becoming popular these days. Such drains were installed along the Mugling-Narayangadh road sector and are now being used in the Narayangadh-Butwal sector of the Mahendra Highway. Such drains not only expedite the construction duration but also increase the overall quality of construction with enhanced aesthetics. Further innovations can be made by designing these elements having interlocking arrangement, which has not been practiced yet.

Hume pipes have been used in roads for cross drainage work. Box culverts and slab culverts are also extensively used in Nepali roads but they are constructed cast-in-situ. Such items are widely used as precast elements elsewhere and can also be practiced in Nepal as precast concrete elements with or without prestressing. Precast culverts may significantly reduce the construction duration of a road project.

Many other precast products are popular in road construction elsewhere and will prove beneficial for Nepal too. In particular, cantilever retaining wall appears to be extremely useful in Nepal. National highways, including Nagdhunga-Mugling sector, Mugling-Pokhara sector and Narayangadh-Butwal sector, are in the phase of widening. Unlike for a new road construction, road widening involves a paramount challenge of traffic management. The indirect cost of traffic interruption in busy highways such as Nagdhunga-Mugling road is presumably higher than the direct cost of construction. Therefore, least disturbance to traffic should be a priority in road widening projects. Precast cantilever retaining walls may effectively serve this purpose by eliminating several time-consuming steps of constructing a cast-in-situ reinforced concrete cantilever retaining wall, namely, the need of site preparation, reinforcement placement, formwork and shuttering work in narrow working spaces, casting of concrete and hardening of concrete. Crib wall is another globally popular product that may be quite useful in Nepali roads and infrastructures for earth retention. Precast concrete elements can be used to construct crib walls in a short duration.

Figure 5

Eco-friendly grass paver with holes for water percolation and grass growth

Water Supply and Sanitation

Hume pipe is a great innovation in the field of precast concrete with profound impact on water conveyance worldwide. Hume pipes are extensively used for water conveyance and sewerage management in Nepal. Figure 6 shows the Hume pipes produced for the national pride Melamchi Water Supply Project. Hume pipe construction technology was invented in Australia by Hume brothers in 1910. Traditionally, it was produced by using spinning technology employing centrifugal force. Hume pipes were so popular that any reinforced concrete tubular pipes are now called Hume pipes. These days Hume pipes can be cast traditionally using spinning technology or can be cast using vertical vibration casting method by using zero slump (dry cast) concrete (MIHPUPL, 2022). While Hume pipes are quite popular, they are bulky elements thus associated with a challenge of transportation. Another popular precast concrete product used in water supply sector is well ring. Well ring is produced locally in various places in Nepal.

Figure 6

Hume pipe production in Kavrepalanchok for the Melamchi Water Supply Project

Electrification

Prestressed concrete (PSC) poles are among the most visible precast and prestressed concrete elements in Nepal. PSC poles in Nepal are usually made in 8 m, 9 m and 11 m height with typical cross section at the bottom as 290 mm × 90 mm, 315 mm × 105 mm (or 300 mm × 140 mm) and 400 mm × 150 mm, respectively (BN Mahto Group, 2022). The poles are made tapering with the top width less than or equal to half of the bottom width. It is because of the prestressing, slender poles with length to thickness ratio exceeding 80 are possible. PSC poles are in production and use for several decades and Nepal appears self-reliant on PSC poles.

Buildings

Building construction is a large domain of application of precast and prestressed concrete technology. Various structural and non-structural components of buildings can be made of precast concrete. They may include the footing, column, beam, slab and wall. Precast concrete technology has brought remarkable contribution to the fast construction of high rise buildings throughout the world. Building construction by using precast construction is sometimes characterized into different systems, namely, large panel system, precast frame system and total precast system. A number of medium to high rise buildings were constructed using large structural wall panels supporting the slab panels with no need of frames. Precast frame system employs precast columns and beams with suitable connections. Total precast system is sometimes considered as the state-of-the art method of precast building construction. As the name suggests, all concrete components in this system are precast components.

Above mentioned systems of precast construction have not been widely used in Nepal yet. The dominant method of building construction in Nepal relies on frame construction either of cast-in-situ reinforced concrete or of structural steel. Therefore, application of precast concrete technology in building construction in Nepal is mostly limited to wall and slab panels. Perhaps, the first structural scale precast and prestressed concrete company in Nepal was established in Bhaktapur in 1990s. Prestressed slab panels from the company were used to construct some large span institutional buildings in Kathmandu valley. After the 2015 Gorkha earthquake, a company was established in Chitwan. Successively, two more companies were established in Kathmandu valley. Currently, at least three companies produce hollow core precast prestressed concrete panels in Nepal based on machine casting on long casting beds with length up to 90 m.

Prestressed hollow core panels are used in framed buildings made of steel as shown in Figure 7. Such panels can be used to construct the slab of buildings made of reinforced concrete frames too. Figure 8 shows a building in Kathmandu that employed 120 mm thick hollow core prestressed panels for slab construction and 90 mm thick hollow core wall panels for wall construction. Compared to half-brick masonry, wall constructed using 90 mm thick hollow core panels can be approximately 56% lighter and approximately 60% more insulating (Gautam, 2022). The panels are lightly prestressed with longitudinal reinforcement. Owing to these benefits in addition to the possibility of fast construction, these panels are gaining popularity for constructing commercial and industrial buildings such as the camp building of a hydroelectric project as shown in Figure 9. Concrete panels of 50 mm thickness and prestressed H-posts have been used in constructing cost-effective buildings (Figure 10). This technology has a prospect to contribute to the People's Housing Program (Janata Awas Karyakram) initiated by the government of Nepal.

Figure 7

Precast prestressed hollow core slabs used in steel frame buildings (Chitwan and Kathmandu)

Figure 8

Use of precast prestressed hollow core wall and slab panels in a RC frame building, Kathmandu (during and after construction)

Figure 9

90 mm thick hollow core wall panels used in a hydropower camp building, Myagdi (during construction and during finishing)

Figure 10

Cost-effective buildings constructed using precast H-posts and panels in Chitwan (community building on the left and residential building on the right)

Compound Wall

Compound wall construction using precast H-posts and panels has become popular lately. However, such walls should be constructed by properly considering the lateral loads such as wind. With proper design, precast panels can be used with sturdier posts made of concrete or steel as shown in Figure 11. In the absence of such considerations and less regard for the quality of precast products, some walls are seen collapsed. Proper design and good quality control of precast products are essential.

Approximately similar structural arrangement is employed in the construction of earth retaining structures called soldier piles. H-piles (mostly steel) are driven into the ground and laggings made of timber or concrete panels are inserted in between the H-piles. The lateral earth pressure is transmitted by the laggings to the H-piles. Precast concrete panels are useful for the lagging structures. Perhaps the first application of such a structure was made by an industry along Narayani River in Bharatpur, Chitwan. This type of structure is a slimmer, faster, stronger and aesthetically pleasing alternative to traditionally used gabion walls for river training works. Sudurpaschim Province may get benefited by constructing soldier piles for river training and flood plain reclamation.

Figure 11

Precast concrete panels used for compound walls (left: polished 50 mm thick panels with precast concrete H-posts; right: 120 mm thick panels with steel posts)

Bus Shelter

An innovative and cost effective precast concrete bus shelter was recently constructed (Sarthak Concrete Pvt. Ltd., 2022). As shown in Figure 12, the 6-seater bus shelter (Pratikshalaya) employs precast H-posts and panels, and follows a minimalist design approach. The structure was constructed in just two days at the site. The cost of construction can be 50% or lower compared to traditionally practiced reinforced concrete structures of similar functionality. This type of bus shelter has huge scope along various roads and public places throughout Nepal.

Figure 12

Precast concrete bus shelter (Pratikshalaya) in Gulmi

Research and Development

Precast concrete producers should maintain a strict quality in every step including material selection, processing, mixing, casting and curing. Material test should be conducted routinely. Sometimes, structural tests are also performed at the factory site. Since structural applications of precast and prestressed concrete elements is relatively unfamiliar in Nepal, suppliers of such elements sometimes demonstrate the strength of the elements through field tests. Figure 13 shows a structural test of the compound wall products by a precast concrete supplier in Bharatpur, Chitwan. A panel was applied a gradually increasing lateral load until failure to examine the capacity of the panel and the posts.

Research and development is an integral component for the success of a precast and prestressed concrete producer. Products should be developed to cater the needs of the Nepali market and the products should be tested through authentic research. Accordingly, two master's research studies have been conducted by engineering graduate students in Kathmandu University in collaboration with the precast and prestressed concrete supplier in Chitwan. Experimental studies were conducted to examine the performance of the joint systems of prestressed hollow core slab panels (Adhikari, 2018) and to evaluate the performance of the H-posts for compound walls (Chaudhary, 2018; Gautam et al., 2023). Further research and collaboration will be helpful to promote the application of precast and prestressed concrete technology for the development of Nepal.

Figure 13

Field level demonstration test to investigate the performance of a precast concrete compound wall

Future Prospects

Compared to the advancement of precast and prestressed concrete technologies in the world, Nepal is in a preliminary stage of their implementation. While Bagmati Province appears to be relatively ahead of other provinces towards the production and use of precast and prestressed concrete producers, Sudurpaschim Province appears to be relatively backward. Awareness of such technologies is scarce in Nepal both at the public level and at the engineering community. No official records for the history of prestressed bridges construction in Nepal spanning 50 years indicates the lack of awareness among the engineering community. Therefore, we should focus on awareness and education about precast and prestressed technology. Minimum level of standards should be developed. Precast and prestressed concrete products and processes should be standardized.

Precast and prestressed concrete technologies have several advantages but they have challenges too. Transportation of large elements from a production site to a construction site can be difficult and costly. Handling of those elements may require mechanical equipment such as overhead cranes. Connection of discrete members requires special joints, proper design and meticulous construction skills. Unique aspects of formwork and propping requirement due to increased span length were discussed in section 3.2. The challenges and unique aspects of precast and prestressed construction in contrast to the reinforced concrete construction should be properly understood. Measures for quality control should be practiced both by the regulatory institutions and by the producers. As the technology and products are at the introductory stage in Nepal, any compromise in quality of work by a producer or a supplier may jeopardize the entire industry.

Academic research institutions should focus on applied research suitable to the domestic market. Local needs can be catered through applied research that aim to expedite infrastructure development by optimally utilizing domestic resources. Concrete is made from local materials and local human resources, and hence its use should be promoted to exercise self-reliance for national development. Construction professionals, contractors and workers should be trained for the use of precast and prestressed concrete technologies. When conceptualizing any infrastructure construction project, precast and prestressed concrete technologies should be discussed and analyzed as alternative technologies to the conventional reinforced concrete construction. Benefits of fast and economical construction should be considered while conceptualizing construction and upgrading projects.

Conclusion

Precast refers to the spatial location of the concrete element while prestressing refers to the stress state of the element. Therefore, a precast element may or may not be prestressed and a prestressed component may or may not be precast. Nevertheless, the two are prominent technologies of concrete and are associated together particularly by producers producing precast concrete elements prestressed by using pre-tensioning method. Relatively large members, such as prestressed bridge girders, are often cast-in-situ and are prestressed by using post-tensioning method. This paper attempted to document the use of precast and prestressed concrete technology in Nepal. Application of precast and prestressed concrete elements in hydropower, irrigation, road, bridge, electrification, water supply, sanitation and building sectors were highlighted through various examples. Applications in compound wall construction, river training works and bus shelter were also discussed. This paper presented the status and prospects of research and development on precast and prestressed concrete in Nepal. Future prospect of precast and prestressed concrete in Nepal was discussed with an indication for Sudurpaschim Province to focus on awareness creation, trainings, and academic research. This paper recommended the promotion of concrete technology for maximizing the development of infrastructure because concrete ensures optimal utilization of locally available construction materials and human resources. Precast and prestressed concrete technologies offer several advantages and have the prospect to expedite the future construction of Nepal, of course including Sudurpaschim Province.

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Conflict of Interest

The author declares no conflict of interest.

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