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THE BENEFITS AND CHALLENGES OF WOOD IN HIGH CORROSIVE SURROUNDINGS

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Summary: The paper addresses the design strategy of designing the joints of large timber structures for corrosive surroundings like swimming hall facilities. It addresses the blind spots of Eurocode 5 and the shows the analytical and practical approach solving both the technical and economical demands of the project both in design- and realization phase.

KEYWORDS: clt, corrosive environments, large structures, WCTE 2023, Oslo, Norway

1 INTRODUCTION

The city of Oslo has a strong environmental policy with an increased use of timber in public buildings as a strategic part to fulfill this policy. The use of timber was therefore a declared the aim of the design for the new main swimming facilities at Tøyen in Oslo.
Swimming halls have high corrosive demands. Timber has obvious advantages regarding corrosive environments in comparison to ferreous materials.
The approach between Eurocode 2 towards reinforcement and Eurocode 5 towards fasteners, have several similarities. Minimal distances between members as well as mechanisms of force-transfer between base material and reinforcement/fastener.

Though the differences are categoric when it comes to corrosions of metals in concrete versus corrosion of metals in timber. The concrete cover is quantitatively defined for the different concrete types and the design of wood only use qualitative terms like ”metal completely covered with wood”. The solution was to contact researchers, producers and institutions in USA, Germany, Italy, and Norway. Applying the fact that corrosion of metals in wood is aqueous [1] and the range of wood moisture content [2] to be expected for the lifetime of the construction, gave the guidelines for both the overall structural design and especially the details.

2 DESIGN PRINCIPLES

The roof structure of the new main swimming facilities at Tøyen in Oslo is designed as hollow wooden beams in a combination of clt and glued laminated timer. The hollow space within the wooded structure in utilized as a technical floor. The basic design idea behind the roof structure, to something more as merely a technical floor, was to use all surfaces as an active part of the structural system. Hence instead of the classical thinking of a lattice structure with a passive cladding and a passive roof slab, inner the lattice was “omitted” and replaced by the visual surfaces as well as the roof slab forming a hollow beam.

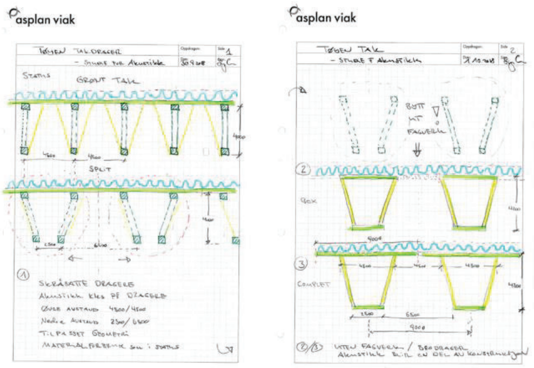

***Figure 1**: Design process – transformation from a spatial additive structure to an integrated solution.*

Additional to the obvious saving in materials by reducing layers also the architectural concept in this way merges completely with the structure.

***Figure 2**: Realisation process: model, mock-up, site.*

The on the top of the structure is a green roof, collecting water which will be used in the bath. The inner surfaces of the structure are for all HVAC and electrical services.

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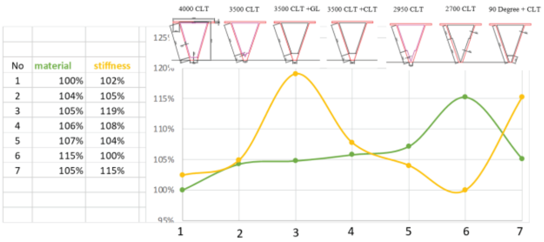
Holes in the surface serve the acoustics. The form of the structure enhances the use of light.

Combined the task is rather straight forward. A span little over 40 meters with a beam height totaling a little over 4 meters. Put simply, the bearing of the roof is always perpendicular to the direction of swimming, whereas the services inside the roof are parallel to the swimming.

3 SECTION COMPOSITION

The structural target of the design was flexural stiffness, answering both to the economical demands of the client and the available production of the market. A CLT production width of 3.5m was chosen to enable a wider range of bidders even though a few producers can deliver withs of 4 meters and more.

A parametric study was performed to compose the final section. A total of seven different compositions were evaluated regarding amount of material used and the stiffness. To enable a comparison, the values were normalized in the following way: the lightest section was defined as 100% - green line, the softest section was defined as 100% - yellow line. In this way the relative values became visually comparable as shown in the Figure 1.



No	material	stiffness
1	100%	102%
2	104%	105%
3	105%	119%
4	106%	108%
5	107%	104%
6	115%	100%
7	105%	115%

Figure 3: *Comparison of the different compositions for the main beam structure.*

The roof is created of several beam sections spaced out with a cc of 4.5 meters. The roof is completed by placing a smaller plate in between the top of two beam elements where the tolerance of the roof is taken up. The final section for construction is as shown in figure 4.

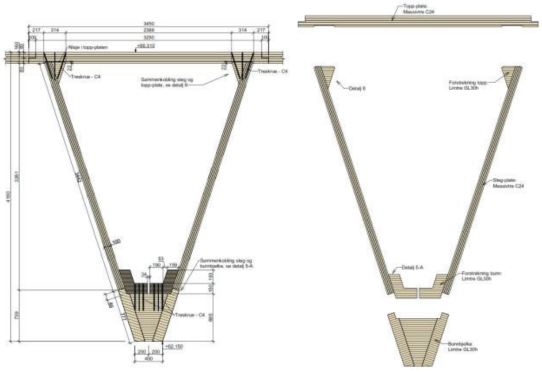


Figure 4: *The final section for construction*

One of the most sensitive points of the functional section "beam + column" is the column foot point. Here an early assessment was made, and a careful material composition and detailing was a successive inter-disciplinary process.

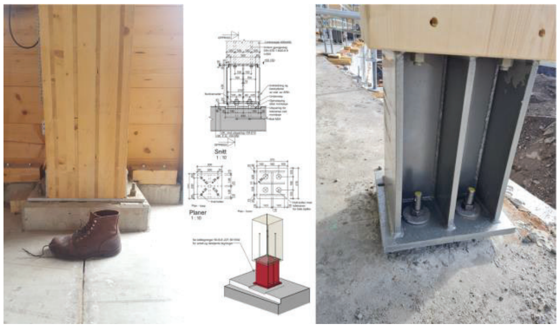


Figure 5: *Column foot point: reference, detailing, site*

4 DESIGNING FOR CORROSIVE ENVIROMENT

It is hard to avoid the use of fully threaded screws when designing large scale spatial timber structures with stiffness as an aim. Unfortunately, the availability fully threaded screws in C5 quality are next to none. Hence the strategy to avoid this problem was twofold: all critical sections being internal and avoiding too high wood humidity. Since the operational humidity and temperature is quite predictable for swimming facilities, it was possible to place the different parts of the construction. This meant designing such that the hygroscopic isotherms had acceptable and non-corrosive values in the zones of maximum forces. This was done in close cooperation with the projects building physic, Fredrik M. Haaland. The following humid zones for order, building and use were defined and placed on the Keylwert-diagram as shown in Figure 2. Thus, it was possible to localize areas non-fitted for connections, but also to verify that other zones had humidity values non-critical in regard to corrosion.

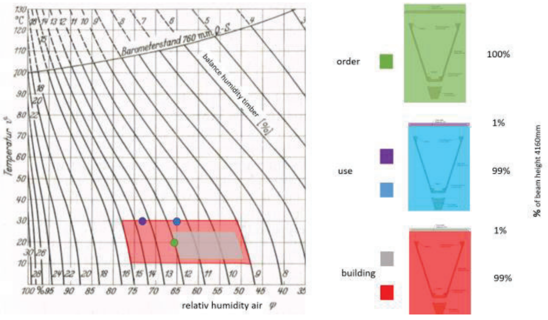


Figure 6: *Humid zones on a Keylwert-diagram.*

In the recent years a strong focus has been set both to assess and to assure the moisture level in wooden constructions. An excellent source used for comparison is "Quality assurance of timber structures" [3] published in Biel 2019. Here different types of buildings, including swimming facilities were evaluated.

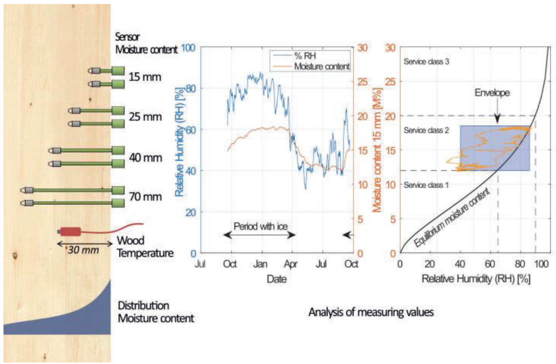


***Figure** 7: Used source for monitoring concept of moisture level [3]*

Due to the large size of the new bath and the different sones of use a monitoring concept reflecting to this was both set out in plan and section of the structure as shown.

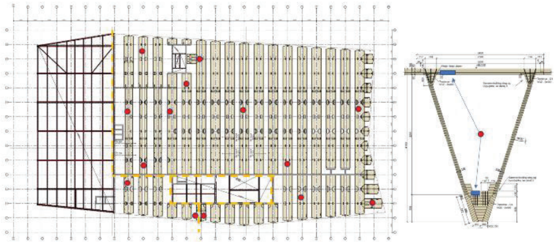


***Figure 8**: Monitoring of moisture in different sones of usage and sectional part of the wood structure.*

5 DESIGNING FOR STIFFNESS

A construction with such large dimensions will always consist of numerous smaller members. Also due to the use for internal services a considerable number of cut-outs must be made. The approach for designing this was straight forward. Starting with a "perfect section" with complete stiffness and no holes gradually increasing flexible boundary conditions and evaluating the influence of material removal. The process of incremented softness is shown in Figure 9 and Figure 10.

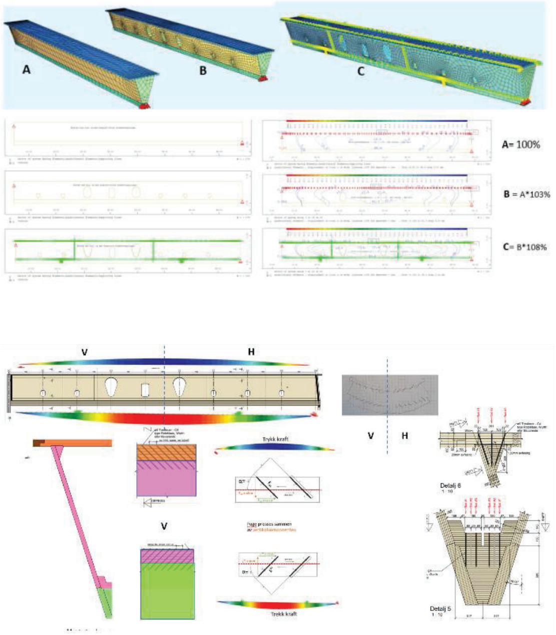


***Figure 9:** The process of incremented softness and link towards detailing in structure*

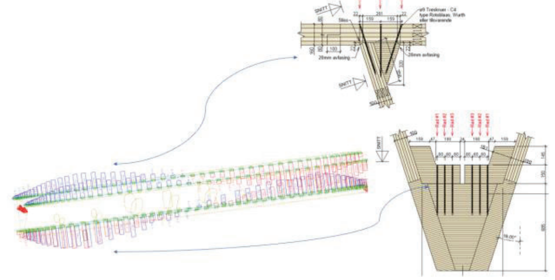


***Figure 10:** Shear flow along the main details of the incremented softness between different elements.*

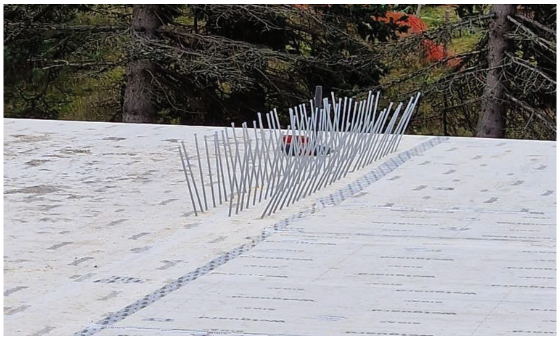


***Figure 11:** Screws from the top plate ready to be drilled in.*

Resulting spring forces in overall modell as comparative bases for the design of fasteners and checking on deformations.

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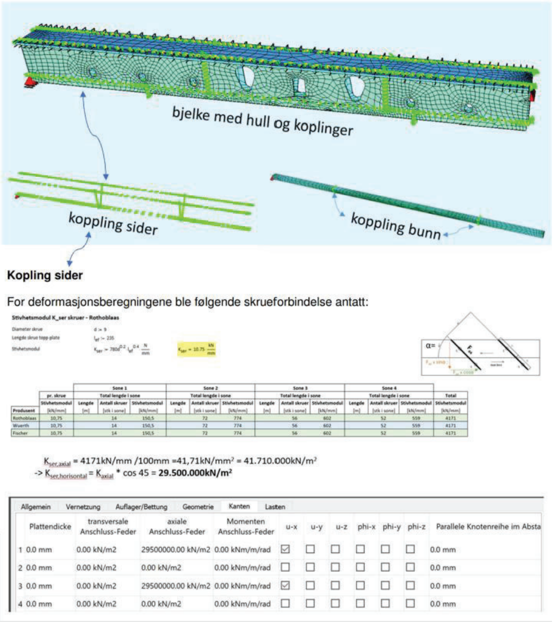


Kopling sider

For deformasjonsberegningene ble følgende skrueforbindelse antatt:

Stivhetsmodul K_ser skruer - Rothoblaas

Diameter skrue $d := 9$

Lengde skrue topp plate $l_{ef} := 235$

Stivhetsmodul $K_{ser} := 780 d^{0.2} \cdot l_{ef}^{0.4} \cdot \frac{N}{mm}$ $K_{ser} = 10.75 \frac{kN}{mm}$

	pr. skrue	Sone 1			Sone 2			Sone 3			Sone 4			Total
		Total lengde i sone			Total lengde i sone			Total lengde i sone			Total lengde i sone			
	Stivhetsmodul	Lengde	Antall skruer	Stivhetsmodul	Lengde	Antall skruer	Stivhetsmodul	Lengde	Antall skruer	Stivhetsmodul	Lengde	Antall skruer	Stivhetsmodul	Stivhetsmodul
Produsent	[kN/mm]	[m]	[stk i sone]	[kN/mm]	[m]	[stk i sone]	[kN/mm]	[m]	[stk i sone]	[kN/mm]	[m]	[stk i sone]	[kN/mm]	[kN/mm]
Rothoblaas	10,75		14	150,5		72	774		56	602		52	559	4171
Wuerth	10,75		14	150,5		72	774		56	602		52	559	4171
Fischer	10,75		14	150,5		72	774		56	602		52	559	4171

$K_{ser,axial}$ = 4171kN/mm /100mm =41,71kN/mm² = 41.710.000kN/m²

-> $K_{ser,horisontal}$ = K_{axial} * cos 45 = **29.500.000kN/m²**

	Plattendicke	transversale Anschluss-Feder	axiale Anschluss-Feder	Momenten Anschluss-Feder	u-x	u-y	u-z	phi-x	phi-y	phi-z	Parallele Knotenreihe im Absta
1	0.0 mm	0.00 kN/m2	29500000.00 kN/m2	0.00 kNm/m/rad	☑	☐	☐	☐	☐	☐	0.0 mm
2	0.0 mm	0.00 kN/m2	0.00 kN/m2	0.00 kNm/m/rad	☐	☐	☐	☐	☐	☐	0.0 mm
3	0.0 mm	0.00 kN/m2	29500000.00 kN/m2	0.00 kNm/m/rad	☑	☐	☐	☐	☐	☐	0.0 mm
4	0.0 mm	0.00 kN/m2	0.00 kN/m2	0.00 kNm/m/rad	☐	☐	☐	☐	☐	☐	0.0 mm

Figure 12: *The process of incremented softness – shell structure modelling principle for a single beam analysis.*

This method of increment made it possible to evaluate the potential of influence quite precisely regarding both forces and deflection. It is important to point out that the use of laminated shell-elements and a complete 3D model of the structure is imperative to assess a reliable result.

One of the most delicate details in the whole project is the connection of the bottom part of the beam. Here a considerable spectrum of solutions was evaluated according to stiffness and feasibility on site.

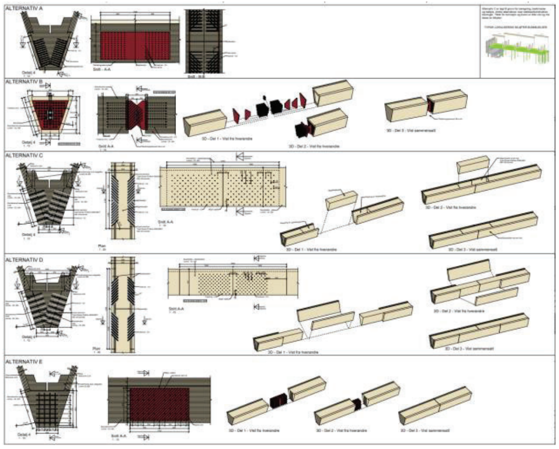
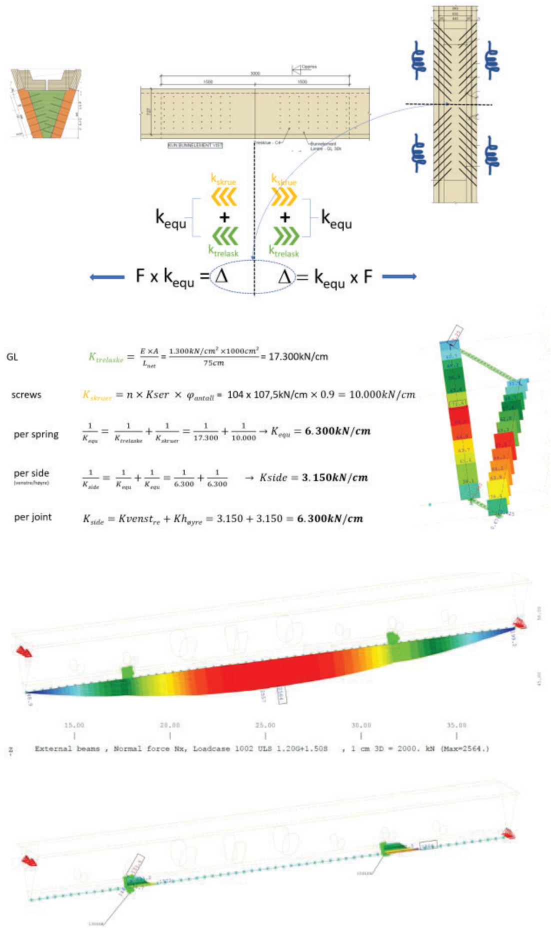


Figure 13: *Variation study of tension detail.*

This was important both due to the high-tension forces, 2.5MN, as well as this is a non-redundant part of a simple-span structure. Before application in the complete model a simple comparative study of stiffness and robustness was executed with the aim to verify the design target.



F x k_{equ} = Δ   Δ = k_{equ} x F

GL $$K_{trelaske} = \frac{E \times A}{L_{net}} = \frac{1.300kN/cm^2 \times 1000cm^2}{75cm} = 17.300\text{kN/cm}$$

screws $$K_{skruer} = n \times Kser \times \varphi_{antall} = 104 \times 107{,}5\text{kN/cm} \times 0.9 = 10.000kN/cm$$

per spring $$\frac{1}{K_{equ}} = \frac{1}{K_{trelaske}} + \frac{1}{K_{skruer}} = \frac{1}{17.300} + \frac{1}{10.000} \rightarrow K_{equ} = \mathbf{6.300kN/cm}$$

per side (venstre/høyre) $$\frac{1}{K_{side}} = \frac{1}{K_{equ}} + \frac{1}{K_{equ}} = \frac{1}{6.300} + \frac{1}{6.300} \rightarrow Kside = \mathbf{3.150kN/cm}$$

per joint $$K_{side} = Kvenst_{re} + Kh_{øyre} = 3.150 + 3.150 = \mathbf{6.300kN/cm}$$

Figure 14: *Tension force distribution – max value 2.5MN, and values at planned site-connections 1.5MN (60%).*

Due to the importance of the on-site tension-connection and the harsh conditions of a swimming hall the following N+1 approach was taken: a combination of a mechanical and glued solution was chosen. In this way both the screws and the glue are independently able to transfer the force at intersection. The design suggested using a 2-component glue solution complying both to the EN 301 as well as low-contact-pressure with allowable thickness around 1.5mm to enable detail-deviations on site. Several rounds were taken with different producers, but the suggested design was clarified in a series of structural-workshops resulting in a 11 step detail description including temperature, humidity, application time shown on the next page in figure 15.

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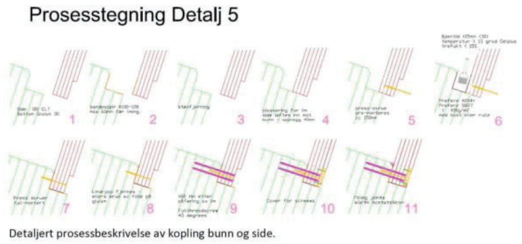
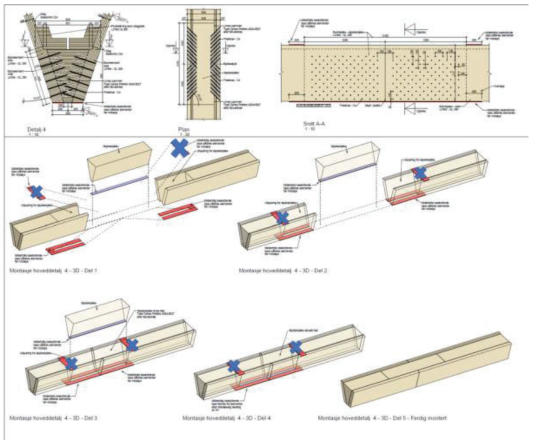
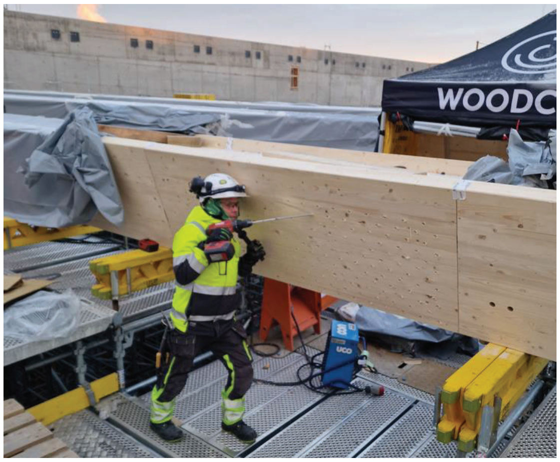


***Figure 15**: 11 step process of an on-site gluing according to EN301 and ETA demands to glue and CLT*

This early working on a high level of detail and practical issues formed the secure basis for a precise description in the tender documents and later a guideline for montage on the site.





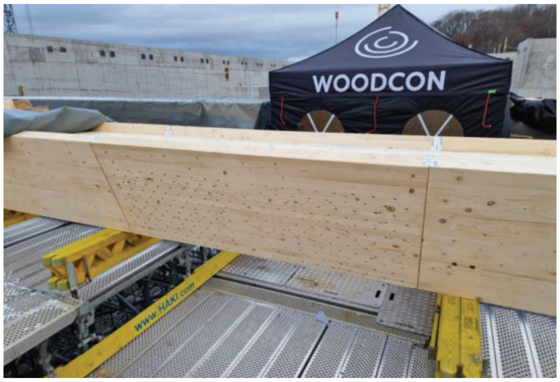


***Figure 16**: Final detailing and realisation on site*

6 CONCLUSION

The New Tøyenbath in Oslo is a project extending boundaries regarding size, functionality and corrosive demands. When compiling such a project this demands the full and continuous focus on details in material, humidity, craftmanship and process of building. While approaching the structural concept and key details of the project a cooperation and open-source approach has been key to developing a contractable and buildable project. Client with a strong vision, early discussions with producers of wood and fasteners. Simple calculations in early phases checking the feasibility of key details and the consequent use of sketches and BIM to navigate between client, producers, and design work. Every project has its delicate points. When realizing a project in C5 environment, success is an incremental process where client, material producers, companies on site and design team will only succeed together.

ACKNOWLEDGEMENT

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