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INNOVATIVE SOLUTION FOR SUSTAINABLE ROAD CONSTRUCTION

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ABSTRACT
The industrial and infrastructural developments in the past mainly focused on economic development. After the Brundtland commission report on sustainable development it was realized that the development should happen considering the future of the Planet Earth and the lives of our successors. In the recent years Kyoto Protocol and Paris summit have put even more emphasis on sustainable development. With the understanding of what causes the impact on our natural environment, CO_2 emission has been accepted as one of the quantitative measures defining sustainability of a project. Road construction activities are a large contributor to CO_2 emissions in Canada. Conventional practices, as discussed, are result oriented and focus only on providing the required structural capacity of roads and highways for the expected traffic condition. Nowadays there are innovative technologies that offer the same structural capacity while using less amount of material and activity required to build the roads which in turn will result in less CO_2 emission.

This paper discusses an innovative solution utilizing Geocells made from nano polymeric alloy to build roads. Two design options, one the conventional method and the other using high strength polymeric Geocells reinforcement are discussed. The findings from the research illustrate that by using the high strength Geocells reinforcement, both the cost of road construction and corresponding CO_2 emissions are greatly reduced compared to the conventional construction alternative. It is illustrated in detail how using innovative geosynthetic alternatives can save up to 20% of CO_2 emissions during the life cycle of a road infrastructure.

KEYWORDS: Road Construction, NPA Geocells, Sustainability, Cost Saving, CO_2 Emission

INTRODUCTION

Sustainable development is defined as development that meets the needs of present without compromising the ability of the future generations to meet their own needs (WECD, 1987). Lippiatt (1999) indicated that the construction industry consumes 16% of water; 25% of raw timber; 40% of stones, sand and gravel; and 40% of the total energy produced in the United States on an annual basis. Chong et al. (2009) noted that sustainable construction aims to achieve the sustainable development objective through the use of sustainable technology and knowledge; however, he mentioned that the construction industry still follows the conventional practice that leaves significant environmental and carbon footprint. Conducting research on the baseline perception of sustainability in the construction industry, Chong et al. (2009) also identified that the knowledge of sustainable construction is fragmented within the industry and construction stakeholders do not have a platform to integrate that knowledge. For this reason, the construction industry must look for ways that comply with the basics of sustainable development concepts. This paper intends to share an experience of an innovative design technology that a takes a stride towards sustainable construction to the civil construction and engineering community. Road construction is one of the major contributors to the construction industry as it requires a huge amount of resources that are costly and hard to replace. This challenges sustainable development with issues such as: use of construction material (especially, mining virgin aggregates), hauling material to the construction site, and the process of onsite construction which uses heavy construction equipment which emit carbon dioxide and other pollutants to the environment.

Sustainability cannot be achieved without addressing all three pillars of sustainable development which are environment, economy and society. Environmental aspects of sustainability have received the most attention recently among the other factors. CO_2 emission is looked into as a tangible measure of how environmentally-friendly a project is; the lower the CO_2 emission from a development activity the more attractive it is from a sustainability point of view. The economic pillar of sustainability that requires actions to be justified through the most equitable and financially logical way possible has also attracted attention over the years. However, the most economical way is not always the most sustainable way. Although one approach might have the highest rate of return from an economic perspective, it cannot prevail over the final decision before taking the other two pillars of sustainability into consideration. More than often, long term benefits should be considered over short term ones in order for a decision to be in line with sustainable development concepts (Doane and MacGillivray, 2011). The third pillar of sustainable development, which has not been researched as much as the other two pillars, is the social sustainability concept (Dempsey et al., 2009): “Social sustainability is based on the concept that a decision or project promotes the betterment of society. In general, future generations should have the same or greater quality of life benefits as the current generations do” (Wanamaker, 2016).

The development budget is always a big challenge for rural Albertan communities. In most cases, besides the budget allocated by the government, their only source of revenue is taxes paid by the residents. Accessibility is a key factor in measuring social equity, which encourages more residents to stay in their community. Road infrastructure among other factors will encourage more facilities and services in the community, and that results in a more sustainable community. Innovative construction techniques are required to enable these communities to afford construction costs of the road which in turn will keep their society sustainable while keeping the economy at balance as well.

The previous paragraph demonstrated how social and economic factors are closely connected to each other in the rural communities; meaning it is crucial for rural communities to find innovative methods to reduce the cost of building infrastructure. Among other methods, nano polymeric alloy (NPA) Geocells can be employed to reduce the cost of road construction activities in rural communities which introduces a new path towards social and economic sustainability. Pokharel et al. (2016) showed that using NPA Geocells can reduce CO_2 emissions of road construction activities up to 40% which is the third pillar of sustainable development. In the next sections it is discussed how NPA Geocells will reduce ownership costs of the road infrastructure, helping local communities in their journey towards a more sustainable community.

This paper introduces an innovative solution utilizing state-of-the-art geosynthetic reinforcement material that will help build roads in a more sustainable manner. Two design options, one the conventional method and the other using high strength polymeric Geocells made from nano polymeric alloy are discussed. The findings from the research illustrate that, using the high strength Geocells for base course reinforcement, both the cost of road construction and corresponding CO_2 emissions are greatly reduced compared to the case of the conventional construction alternative. It is illustrated in detail how using innovative geosynthetic alternatives can save up to 20% of CO_2 emission during the life cycle of a road.

NPA GEOCELLS

US Army Corps of Engineers developed the concept of cellular confinement mainly to stabilize beach sand in the 70s (Webster, 1979). The cellular confinement system, commonly known as Geocells, has gone through thorough testing over the years. Until a decade ago, HDPE was the only commercially available Geocell material option. Since then, Neoloy-based NPA Geocells have been developed which add strength and multiply the modulus of granular soils for a period of time extending beyond the economic life of the road, and these Geocells have taken over as the most reliable choice.

NPA Geocells are made from polymeric nano-composite alloy of polymer/polyamide nano-fibers dispersed in a polyolefin matrix that possesses the ductility of high density polyethylene and the dimensional stability and creep resistance of polyester. The properties of NPA Geocells are given in

Table 1 and Figure 1 shows its fully stretched form at the base course ready to be filled with granular infill.

Table 1 Properties of NPA Geocell (reproduced from Pokharel et al., 2016)

Description	Value
Neoloy Material	Polymeric nano-composite alloy
Material strength at yield	24 MPa
Strength at yield (wide-width test)	21.5 kN/m
Cell height of Geocell	150mm
Distance between weld seams	330mm
Cell wall thickness	1.1mm
Coefficient of soil-cell friction efficiency	0.95
Coefficient of thermal expansion	<115 ppm/^{0}C
Brittle temperature	<minus 70^{0}C
Long term plastic deformation at 65^{0}C (load 6.6 kN/m)	<1.3% deformation

Figure 1Stretched NPA Geocells ready to be infilled with gravel

DESIGN BASIS

AASHTO 1993 pavement design method is modified when the base or sub-base layers of road structure are reinforced with Geocells. AASHTO 1993 design method defines a layer coefficient for different layers used in a pavement structure which then define the Structural Number (SN) of the pavement. SN is used to determine the life of the pavement in respect to how many numbers of Equivalent Single Axle Load (ESAL) can be applied before it reaches its terminal serviceability. The coefficients for the base and sub-base layers is a function of that layer's elastic modulus as defined in Equation 1and Equation 2.

$$\boldsymbol{a_{base} = 0.249 * (log\, E_{base}) - 0.977} \qquad \textit{Equation 1}$$

$$\boldsymbol{a_{subbase} = 0.227 * (\log E_{subbase}) - 0.839} \qquad \textit{Equation 2}$$

Alberta Transportation (AT) uses the values introduced in American Association of State Highways and Transportation Officials (AASHTO) 1993 with some local calibration as shown in Table 2 (AT & U, 1997).

Table 2 Layers' Coefficient by AT and AASHTO 1993 Guide

Layer	Alberta Transportation Layer Coefficient	AASHTO 1993 Layer Coefficient
Asphalt Concrete	0.40	0.44
Granular Base Layer(GBC)	0.14	0.14
Granular Sub-Base Layer (GSBC)	0.1	0.11

Geocells reinforce the road structure through different mechanisms. Base layer is reinforced through improvement of wheel load distribution and lateral restraint of base course material (Giroud and Han, 2016). Pokharel et al. (2010) showed that depending on the quality of the base material the layer's resilient modulus can be increased by as much as 7.5 times. The same study indicates that the improvement factor is between 3.4 to 7.5 times. While designing paved roads using NPA Geocells the lower range of the spectrum, an improvement factor of 3.5, is used. Using Equation 1and Equation 2 the modified layers' coefficient for the reinforced zone of base and subbase layer would be 0.27 and 0.22, respectively. These values are used to estimate the SN for a given structure and to determine the number of ESALs a pavement structure can endure before reaching the threshold of failure.

DESIGNING WITH NPA GEOCELLS

As described in the previous sections employing NPA Geocells will result in pavement layers' modulus improvement, which in turn results in reduction of the required thickness of each layer to achieve the desired strength. A typical road in rural Alberta will be exposed to be 500,000-1,000,000 ESALs during its service life. Using typical design parameters suggested by AT and shown in Table 3 the unreinforced pavement section would consist of 125mm of Asphalt Concrete and 340mm of GBC while the reinforced pavement structure will consist of 100mm of Asphalt Concrete and 240mm of GBC on a 30MPa subgrade**.** Figure 2 shows the unreinforced and NPA Geocell reinforced equivalent design sections.

Table 3 Pavement Design Parameters

Design Parameter	Value
Total ESALs	500,000
Reliability (R)	85%
Overall Standard Error (S_0)	0.45
Initial Serviceability Index	4.2
Terminal Serviceability Index	2.7
Asphalt Concrete Layer Coefficient	0.40
Unreinforced GBC Layer Coefficient	0.14
Reinforced GBC Layer Coefficient	0.27
Unreinforced GSBC Layer Coefficient	0.10
Reinforced GSBC Layer Coefficient	0.22
Subgrade Resilient Modulus	30 MPa

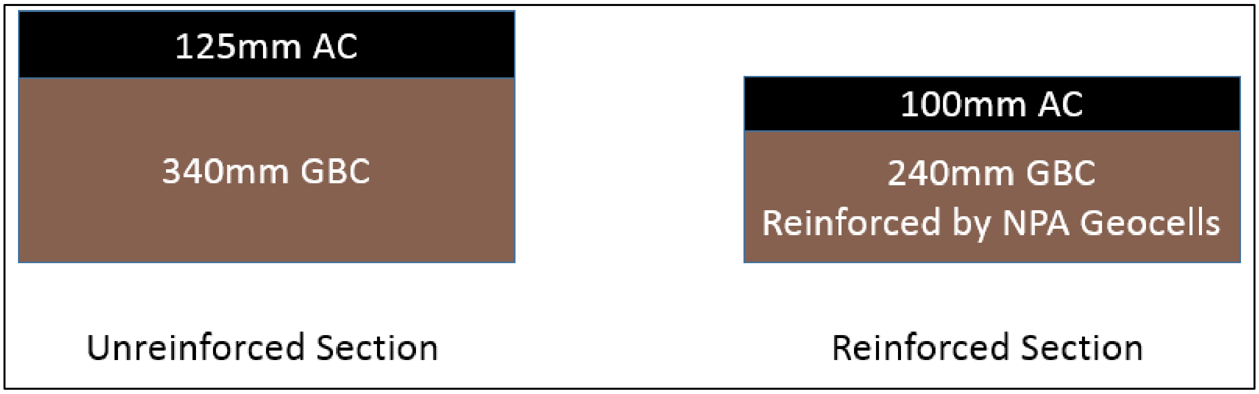

Figure 2 Typical unreinforced pavement section vs. typical NPA Geocell reinforced section

Next section will discuss a case study of a project completed in rural Alberta for the Village of Ryley.

CASE STUDY: VILLAGE OF RYLEY MAIN STREET RECONSTRUCTION

The Village of Ryley located in Beaver County in central Alberta needed to reconstruct their 1.8km long 50 Avenue which is the Village's main street. There was no record of when this street was constructed; however, as shown in Figure 3 it needed immediate attention. NPA Geocells as base course reinforcement was proposed in the project to reduce the cost of ownership for the Village, which like every other rural municipality in Alberta, was struggling with budget limitations. The Village accepted the proposal to utilize NPA Geocell reinforcement in their main street re-construction. The first part of this section intends to demonstrate how the employment of an innovative construction method, in this case NPA Geocells reinforcements, helped the Village to be able to go ahead with the project. Next, the environmental benefits of NPA Geocells in regards to reducing CO_2 emissions as a result of the construction activities will be presented.

Figure 3 Existing condition of the Village of Ryley main street before reconstruction

The estimated traffic for the life cycle of this street was estimated to be 500,000 ESALs. And the subgrade resilient modulus was determined to be 40MPa through in-situ Dynamic Cone Penetration (DCP) tests. The conventional option would have been to construct 100mm Asphalt Concrete pavement over 300mm GBC. With the use of NPA Geocells the layers' thickness were reduced by 25% down to 75mm of AC and 225mm of GBC reinforced with NPA Geocell. It is noteworthy that employing NPA Geocells does not have an adverse effect on the project schedule as installation crew was always ahead of civil earthwork crew throughout the duration of the project.

Figure 4 shows pictures of 50 Avenue being constructed at the base layer with NPA Geocells and at completed stage.

Figure 4 50 Avenue a) during construction of base layer b) completed pavement

a) **Construction Cost Comparison**

The cost-benefit analysis introduced in this section will emphasize on the capital construction cost but does not include the benefits of using NPA Geocells over the life cycle of the road because of absence of recorded operation and maintenance data for a similar project. The authors with some project experience using the NPA Geocells and feedback from the owners can confirm that the life cycle cost savings due to reduced operation and maintenance costs will be huge. The construction rates used in this cost-benefit analysis are the rates used by the construction contractor.

Due to constraints such as existing curbs, existing utilities etc. the final elevation of the finished street had to be kept same as the existing condition. This meant in order to build the new structure the existing ground had to be excavated as much as the proposed structure thickness (300mm in case of NPA Geocells and 400mm in case of conventional alternative). Also, thicker layers meant more material and more effort required to compact and place them. Finally, asphalt concrete, which is an expensive commodity, was reduced by 25% which contributed to the reduction in the project cost. Therefore, the cost-benefit analysis on this capital project cost focused on excavation, amount of granular aggregate required and asphalt layer thickness and assumed all the other items such as mobilizing, demobilizing, surveying, etc. to be the same for both of the alternatives.

Table 4 summarizes the quantities required for each item for the respective alternative.

Table 4 Material Savings for the two alternatives

Item	NPA Geocell Alternative	Conventional Alternative
Excavation	2380 m^3	3173 m^3
Granular Aggregate	8675 MT*	11566 MT
Asphalt Concrete	3016 MT	4022 MT
NPA Geocell	17506 m^2	-

* Metric Tonne

Knowing how much material and construction time was saved, it is a straightforward task to calculate the dollar value of savings as a result of implementing innovative NPA Geocells in the road structure. Figure 5 shows the cost impact of savings in material and also the cost associated with NPA Geocells' supply and installation on this project. Total savings on this project were $135,000, which totaled to approximately 10% of the total construction cost. It is noteworthy to mention that these savings only include capital construction cost comparisons, and ignore the benefits incurred over the life of the road structure. It can be a good topic for future research to study life cycle cost benefits of using NPA Geocells in the road structure.

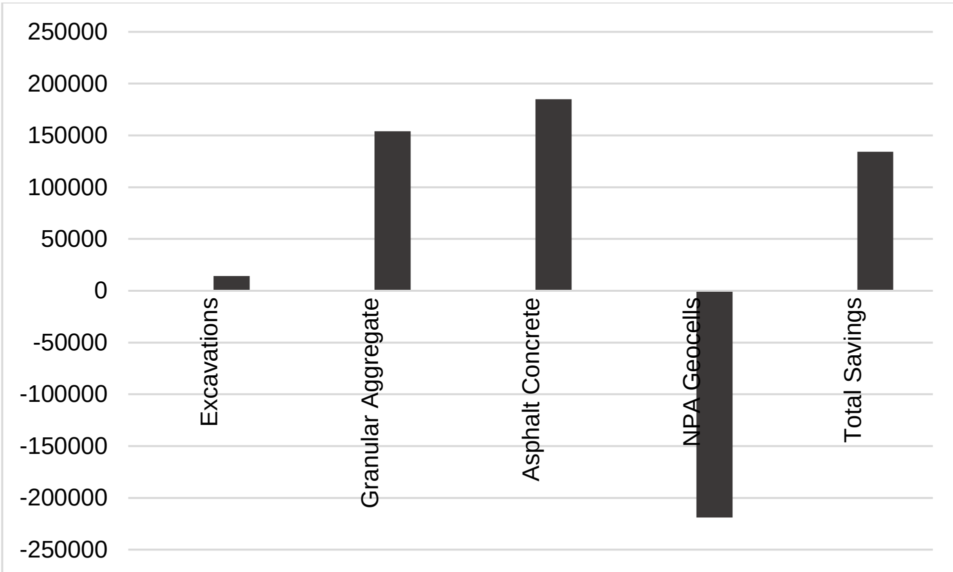

Figure 5 Savings in road construction as a result of using NPA Geocells

As shown in Figure 5, using NPA Geocells reduced the construction cost of the project. This is the money that can be utilized in other parts of the community providing residents with more services and amenities, which means higher quality of life and social equity while also providing them with a reason to stay in their own communities.

b) **Carbon Emission Savings**

The Province of Alberta is struggling to find resources to produce the gravel required for its construction projects. Road construction activities as discussed earlier contribute to the demand for gravel. Scarce resources of gravel will create challenges for construction projects a few of which can be listed as: 1) availability of gravel, 2) high cost of trucking the aggregate to the project location, 3) adverse effect on environmental sustainability (quantified as CO_2 emission). The main contributors to CO_2 emission during road construction are: 1) Gravel production and placement, 2) Gravel hauling, 3) Heavy equipment, 4) Asphalt production and placement. These factors are studied for the case of Village of Ryley main street reconstruction to calculate how NPA Geocells helped reduce the CO_2 emission during the course of road construction.

According to US-EI database (Earthshift, Huntington, VT, the Ecoinvent 3.1 database adjusted for U.S. energy grid inputs), during the production of 1 ton of crushed aggregate 10kg of CO_2 is released into the atmosphere. The same database reports that a transport truck will produce 0.197kg CO_2 for every tonne.km of hauling. Dorchies et al. (2008) reported that to manufacture one ton of asphalt 307kg of CO_2 is produced; the same report indicates the contribution of construction equipment on the CO_2 emission would be marginal therefore their effect is not included in this paper. Also, to produce one kilogram of NPA Geocells, 1.93kg of CO_2 is released. Having these numbers, it is a straightforward job to calculate how much NPA Geocells can contribute to the environment by reducing the required resources which results in reducing CO_2 emissions due to the road construction activities.

Table 5 shows the amount of CO_2 produced as a result of road construction activities in a comparative analysis.

Table 5 CO2 produced as a result of construction activities

Item	Alternative	Quantity	Unit	CO2 (kg/unit)	CO2 (kg)	Reduction in CO2 emission (kg)
Crushed Gravel	NPA Geocell Alternative	8,675	tonnes	10	86,750	28,910
	Conventional Option	11,566	tonnes		115,660	
Asphalt Pavement	NPA Geocell Alternative	3,016	tonnes	52.5	158,340	52,815
	Conventional Option	4,022	tonnes		211,155	
Aggregate Hauling	NPA Geocell Alternative	694,000	t.km	0.197	136,718	45,562
	Conventional Option	925,280	t.km		182,280	
NPA Geocell manufacturing	NPA Geocell Alternative	17,506	kg	1.93	33,787	(33,787)
	Conventional Option	-	kg		-	
					Total:	93,501

As shown in Table 5, using NPA Geocells will result in a reduction of 93,500kg CO_2 emissions on a very small scale project, which is approximately 20% reduction in generated CO_2 due to road construction activities.

DISCUSSION

Sustainability targets of a development project cannot be achieved unless all three pillars of sustainable development are addressed properly. It was mentioned previously that the environment, economy, and society are the three pillars of a sustainable development. Cost definitely plays the most important part in the project development and its sustainability, but comparing the cost directly with the tangible benefit alone will keep the other two pillars at the bay. As shown in the previous headings utilizing NPA Geocell drastically reduces required GBC and asphalt thickness in the road structure. Pokharel et al. (2016) had shown that this reduction contributes to approximately 40% reduction in the CO_2 emissions as a result of the road construction activities. Also, from a cost driven point of view, reduction in layers' thicknesses translates into reduction in project cost. That being said, a cost benefit analysis should be performed on a project specific basis to determine whether reduction required in a layer's thickness will offset the additional cost of NPA Geocells or not. The amount of reduction in CO_2 emissions, which is a quantifiable term for environmental measures, will give evidence that a project is moving towards an environmentally sustainable concept. The cost benefit analysis will prove that the community will have to spend less money for a road that will perform at least equal to conventional options, *more bang for your buck*, and will lead the communities to a more sustainable economy. Finally once communities are able to spend less on their road infrastructure projects, they will have enough budget to provide their members with more amenities and services bringing more social equity to the community.

The 50 Avenue reconstruction at the village of Ryley was due for a long time but the village was unable to meet the construction cost as well as the recurring maintenance cost. The village needed a design that would bring the construction cost within their budget, and bring minimal operation and maintenance costs thereafter. The design for the road was therefore done using high strength NPA Geocell reinforcement. As mentioned before and shown in Table 4 and Figure 5, the innovative design saved almost 10% of the initial investment cost and reduced the quantity of construction material that contributed to 20% reduction in CO_2 emission compared to conventional alternative.

The biggest contributors to CO_2 emission in a road construction project are aggregate manufacturing, asphalt manufacturing, and transportation. NPA Geocells in the village of Ryley project enabled designers to reduce the amount of required aggregate and asphalt, which meant less CO_2 emissions as a result of the construction activities.

The Province of Alberta has started imposing taxes on carbon produced in different industries, and although for a small project such as the case study discussed in this paper it is not a large amount of money, it can be significant amount of money in large scale projects. This gives different industries more incentive to start looking for innovative, environment-friendly methods. Based on a report by Alberta Transportation in 2015, 860km of Alberta roads have been rehabilitated or reconstructed. A simple calculation, assuming NPA Geocells can reduce the asphalt concrete and base layer's required thickness by 25% (as was the case in the case study), shows that there is a potential to save upwards of 44,720,000 kg of CO_2 from being released into the atmosphere which can be of interest from both financial and environmental points of view.

Based on the reports published by Statistics Canada, the rural population in Alberta has decreased from 75% in 1901 to 17% in 2011.This has resulted in an extremely limited budget for the rural local communities which has even led a whole village to be abandoned in some cases.. Table 4 and Figure 5 show how utilizing NPA Geocells in the road structure reduced the initial construction cost while keeping the serviceability of the road similar or better compared to the conventional option. The initial construction cost was reduced by 10% once NPA Geocells were used. This saving can be used towards providing the residents of the Village of Ryley more services and amenities. The social benefits of the enhanced performance of the road include more reliable and safer transportation that is achieved by providing a better quality NPA Geocell reinforced substructure for the pavement in addition to less disruption of the traffic due to less rehabilitation work being required over the life cycle of the road. Alberta Transportation in its 2015-2016 annual report mentions that Albertans need to be smart with their investment on road construction and rehabilitation strategies. The results of this paper indicate that NPA Geocells can be one of the smart ways to invest in road construction and rehabilitation since they maximize the useful life of the road structure while reducing ownership cost and CO_2 emissions. Further studies are required and encouraged by the authors to evaluate CO_2 emission reduction during the life cycle of a road, as the authors believe there will be tremendous savings due to less maintenance and rehabilitation required with the implementation of NPA Geocells in the road structure.

CONCLUSION

Roads are the backbones of a sustainable development plan for a rural village. Better accessibility means better services and amenities in the area, which help retain the rural population and achieve the development's goals. Budget limitations for construction in the rural community have created a situation where the decision makers have started to look for sustainable options and innovative methods to reduce the capital cost of construction, especially in the context of rural Alberta. Using NPA Geocell reinforcement in the project, benefits were realized in all three pillars of sustainable development. The tangible ones are the 10% saving on initial project costs and 20% saving in the CO_2 emission reduction.

This paper has shared the knowledge from a case study on how utilizing an innovative technology can make sustainable construction a reality. The research only looked into the savings in terms of initial cost and carbon emission savings for the comparison. The next step in this research would be to do a complete life cycle cost analysis. As the societal benefits of a sustainable project are still vague in terms of value, a detailed socioeconomic impact study of the road would be another topic.

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