AN ANALYSIS STUDY OF CORRUGATED STEEL ROAD CULVERTS UNDER NORMAL LOAD CONDITIONS IN VIETNAM

TRAN VIET HUNG[1], TRAN QUOC TRINH[2]

[1]*University of Transport and Communications, No 3 Cau Giay Street, Hanoi, Vietnam*
[2]*VITEC Engineering., JSC, No 8, Alley 115 Nguyen Khang Street, Hanoi, Vietnam*
Corresponding author's email: tranviethung@utc.edu.vn

Abstract: *This research provides the basis for developing a corrugated steel culvert (CSC) structural under highway, which can be applied in Vietnam. When a culvert is buried at a shallow depth, vertical pressure and traffic loading transferred onto the roof of the culvert can induce deflections of the culvert. The effect of the traffic load on the response of the culvert depends not only on the magnitude, pattern and speed of the traffic load but also on the pavement structure. The purpose of this paper is to present and analyze the characteristics of the corrugated steel culvert to see its superiority and to investigate backfill height cases to investigate the bearing capacity of the culvert. It is known that soil cover depth influences the obtained values of internal forces, the displacement and stress under nomal load conditions.*

Keywords: *Corrugated steel pipe, culvert, highway in Vietnam*

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I. INTRODUCTION

In recent years lots of highways were constructed in Vietnam. Therefore, there have lots of underpass systems to ensure traffic between two sides of the highway and horizontal culvert to transverse drainage of the highway. In Vietnam, underpass and culvert often constructed by reinforced concrete structures with heavy weight, take a long time for construction of foundation and the phenomenon of non-balance settlement, especially in the area of soft ground. Currently there are many structural and material solutions that can be used to replace traditional reinforced concrete materials. A type of corrugated steel pipe is a lightweight structure, able to withstand large deformation and no need to build concrete foundations was introduced to address these problems. On the highway, traffic load has also increased, this has caused an increase in dynamic loads influencing engineering structures such as bridges and culverts.

Since the 1890s in the United States has used corrugated metal. Form 1958, this technology began to be introduced to Japan, then quickly became widely used by corrugated steel plate ensures increased strength and lightness, making it easy to construct, transport and excel in economy. Corrugated steel culverts are common civil infrastructure components used for underpass, corrugated drainages, traffic tunnels, water supply tanks [1,2]. The corrugated steel

pipes, which are installed three or four decades ago, are approaching the end of their useful service life. The assessment of the longevity of corrugated steel pipes have been studied and tested showed very good performance. The estimated remaining service life to be in the range of 10 to 100 years, which is primarily a function of local environmental conditions (e.g., soil pH, resistivity), corrosion potential, abrasion, and use of protection coating system [3,4,5].

The corrugated steel pipe culvert consists of the thin shell structure and the engineering backfill. The shell steel structure seems to be very flexible and sensitive to normal loads such as passing vehicles and backfill layers [6,7,8]. Corrugated steel pipes with steel plate thicknesses from 2.7 to 7.0mm is corrugated to ensure increased strength and light weight, so it is easy to construct, transport as well as outstanding in economy. Fig. 1 to Fig. 4 shown some practical applications of corrugated steel pipe.

Figure 1. *Corrugated drainage [1]*

Figure 2. *Water supply pipes [1]*

Figure 3. *Tunnel [1]*

Figure 4. *Water tank [1]*

Thus, new technology solution aims to limit technical problems related to acceleration construction capacity, unbalanced settlement of the bed-road at the sewer construction sites and the long life of the sewer corrugated steel structure. Thus, in this paper, a type of corrugated steel is a lightweight structure, able to withstand large deformation and no need to build concrete foundations was introduced to address the above issues. The reasonableness of design methods, construction methods as well as new features in the use of corrugated steel will be demonstrated a corrugated pipe culvert.

II. CHARACTERISTIC OF A CORRUGATED STEEL CULVERT

Due to the thin corrugated pipe, it is capable of deforming under vertical soil pressure (narrowing the vertical diameter of the tube, the diameter of the lateral expansion). As a result, the tube is compressed by soil and sand on both sides, subjected to greater soil pressure, eventually

the vertical and horizontal soil pressure is almost the same value, so it is very stable (show in Fig. 5). Therefore, with corrugated tubes, bending torque is almost ineffective, only axial force works, so even thin steel pipes can withstand great external forces.

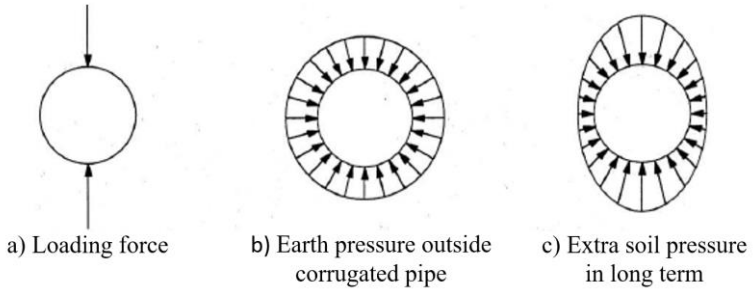


Figure 5. *The operation principle of corrugated pipes*

Selecting the shape and type of culvert depends on several factors, such as the corrosiveness of the soil at the culvert site, the thickness of fill cover, limitation of upstream water surface elevation, hydraulic performance, etc. There are numerous cross-sectional shapes available for culverts and end treatments. The main shape of corrugated steel culverts consists of type 1 and type 2 as shown in Fig. 6a and Fig. 6b, respectively.

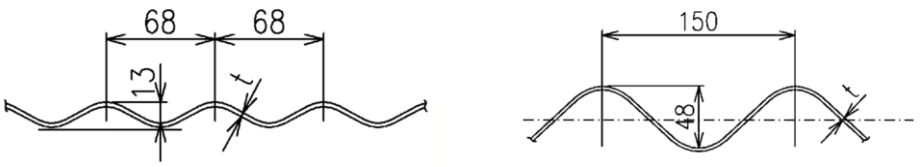
- Type 1: Semi-circle, with pipe diameter from 0.3m to 1.8m, steel plate thickness from 1.6mm to 4mm.

- Type 2: Constructed from bent steel plates, pipe diameter is from 1.25m to 4.5m, steel plate thickness is from 2.7mm to 7.0mm.

a) Type 1

b) Type 2

Figure 6*. Shape of corrugated steel culverts*



a) Type 1 a) Type 2

Figure 7*. Dimensions of two types of corrugated steel pipes*

During the construction process, the soil layers need to be compacted in 30-50cm layers around the pipe body. Due to the principle of external force balance, the steel pipe will self-regulate the appropriate bearing state, therefore, the steel pipe is quite thin but still ensures the bearing capacity.

The material properties and characteristics of corrugated steel plate are described in Tables 1 and 2.

Table 1. *Corrugated steel culvert materials [1,9]*

Nominal diameter	Weight of corrugated steel (kg/m)							Number of bolts required per 1m in length (the set / m)				The mass of the bolts (kg/m)
	t=2.7	t=3.2	t=4.0	t=4.5	t=5.3	t=6.0	t=7.0	Thickness of plate steel	Convex part (A)	Concave part (B)	Total	
2000	201	237	295	331	390	440	510	t≤5.3	43.3	26.7	70.0	20.4
								t≥6.0		53.3	96.6	32.3
2500	248	292	364	407	480	542	630	t≤5.3	48.3	26.7	75.0	21.8
								t≥6.0		53.3	101.6	34.0
3000	295	347	433	483	570	643	750	t≤5.3	53.3	26.7	80.0	23.3
								t≥6.0		53.3	106.6	35.6

Table 2. ***Properties of corrugated steel pipes*** *[1,9]*

Steel plate thickness t (mm)	Cross section area A (cm^2 / m)	Section modulus Z (cm^3 / m)	Moment of inertia I (cm^4 / m)
2.7	32.98	34.74	88.1
3.2	39.10	40.94	104.8
4.0	48.91	50.74	131.9
4.5	55.04	56.80	149.1
5.3	64.86	66.40	177.0
6.0	73.47	74.73	201.8
7.0	85.78	86.53	238.0

To consider the advantages of corrugated steel culverts, some characteristic parameters for culverts selection are considered. Through the comparison of similar and different characteristics between corrugated steel culverts and reinforced concrete culverts, the current popular culverts have shown the outstanding advantages of corrugated steel culverts as in Table 3.

Table 3. *Comparison of characteristics of the two types of sewers*

Types	Corrugated steel culverts	Concrete box culverts
Photos		
Application	Pedestrian tunnels, bridges over small rivers, residential culverts, drainage culverts ...	Tunnels, bridges across rivers, waterways ...
Dimension of culvert	About 1 to 10 m	According to the standard 1 to 6m (under 6m). Oversized dimensions must be designed specifically.
Minimum to Maximum embankment thickness (m)	Up to 6m	According to the standard 0.5 to 6m
Construction properties	. Short construction time (half the time compared to concrete) . No special manipulation or machinery required . Transporting materials easily by manpower	. Long construction time (on-site work) . Common construction method, there are many places that have construct it
Longevity	Approximately 50 years (according to reality in Japan)	Over 50 years

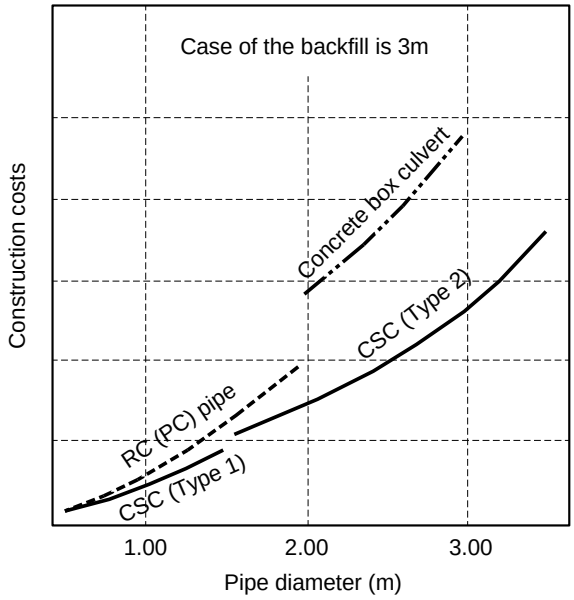


Figure 8*. Economic comparison between types of culverts [1]*

Fig. 8 shows a comparison of different types of culverts. The culverts used to make drainage culverts and underground culverts with a diameter of 2.0 to 3.0m indicate that the reinforced concrete box culvert has a much higher construction cost than the wave steel culverts. For drainage culverts less than 2.0m in diameter, precast reinforced concrete culverts also cost more than corrugated steel culverts. This proves that the economic possibility is fairly consistent when applying corrugated steel culverts.

III. LOAD CAPACITY OF A CORRUGATED STEEL CULVERT

3.1. Description

Some recommendations [1,10], the backfill height on top of steel pipe must be at least 0.65m. However, for steel culverts, the construction with thin backfill is extremely difficult, so we recommend that the backfill on the top of the corrugated steel pipe must be greater than or equal to 1.0m. To see the effect of the embankment layer on the top of the culvert on the load due to backfill layers and vertical load, the steel pipe structure with a diameter of 2.0m and steel plate thickness t = 4mm will be simulated as a calculation example in this study. The backfill thickness was investigated from 1.0 to 3.0 m.

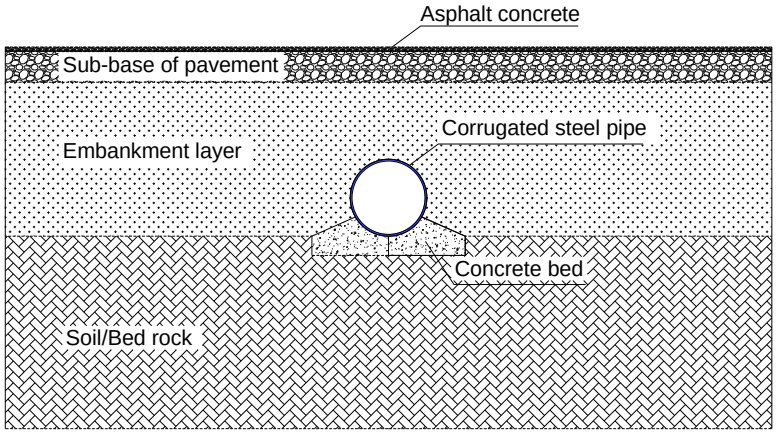
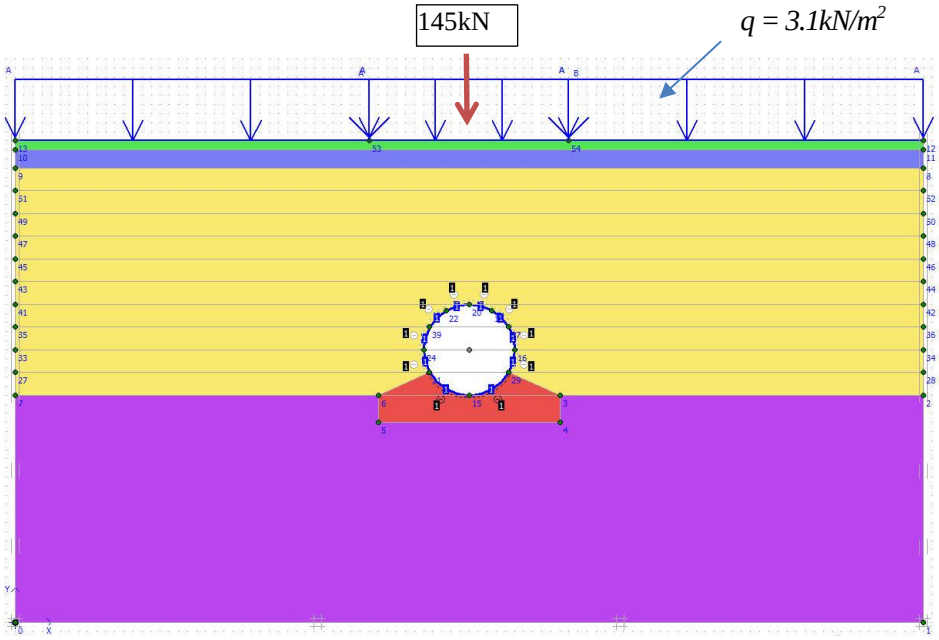


***Figure 9**. Example of corrugated steel culvert*

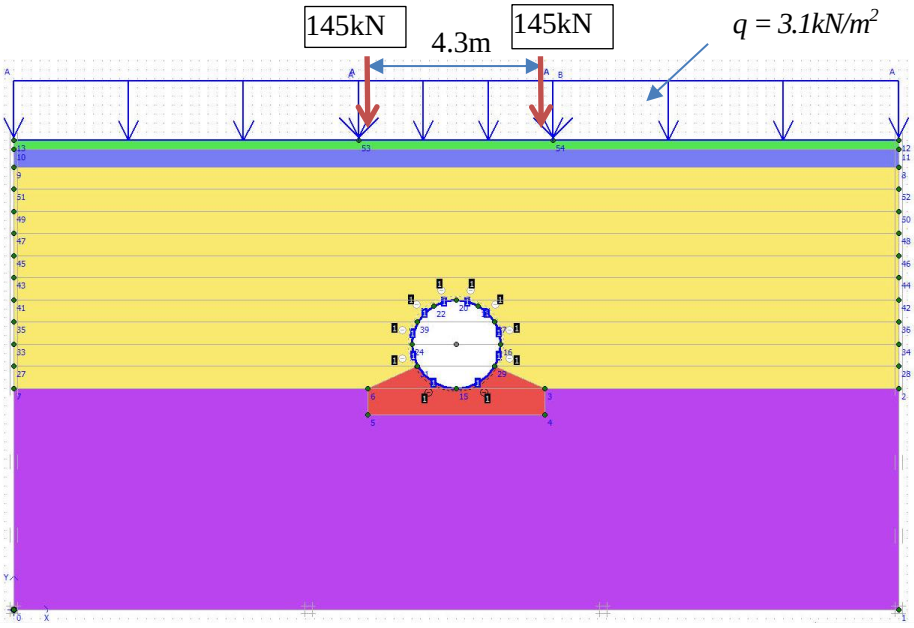
***Table 4.** Input data of this study*

No.	Items	Symbol/Units	Values
I	**Pavement surface**		
1.1	The thickness of the pavement surface	t_s(m)	0.12
1.2	The average density of the surface layers of the pavement	γ_s(T/m^3)	2.3
II	**Pavement sub-base**		
2.1	The thickness of the pavement sub-base	t_b(m)	0.35
2.2	The average density of pavement sub-base layer	γ_b(T/m^3)	1.6
III	**The thickness of the embankment layer on round culverts (0.5m / case)**	H(m)	1.0, 1.5, 2.0and 3.0
3.1	The average density of the embankment layer	γ_0(T/m^3)	1.8
3.2	Internal friction angle	φ(degree)	30

In this study, a corrugated pipe with a diameter of 2.0m was selected as the object for the analysis model with the top embankment layers of 1.0m, 1.5m, 2.0m and 3.0m, respectively. Consider the case of corrugated steel culverts with live load of HL-93 truck in TCVN 11823: 2017 and the road embankment materials are used in Vietnam. Two cases of the wheel axis loads acting on top of the pipe will be considered (Fig. 9a and 9b).



a) Case of 1 axis load



b) Case of 2 axis loads

***Figure 10**. 2D model with uniform load q = 3.1kN/m² and concentrated load Q = 145kN*

3.2. The result and discussion

Fig. 11 and Fig. 12 shown the relationship between total displacement and bending moments with thickness of backfilling, respectively in case of steel plate thickness of 4mm and diameter of steel pipe of 2.0m.

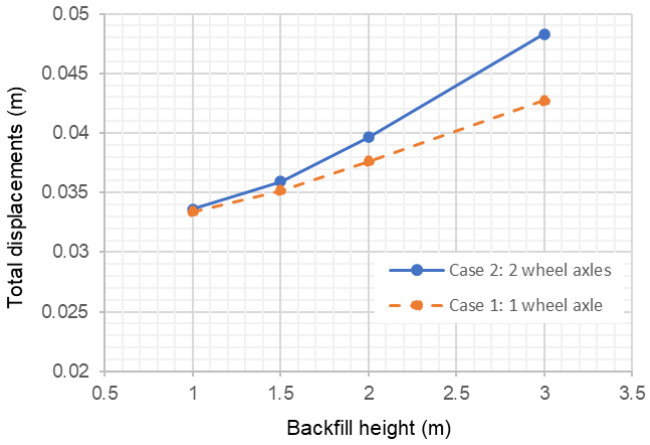


Figure 11. *Relationship between total displacement and thickness of backfill*

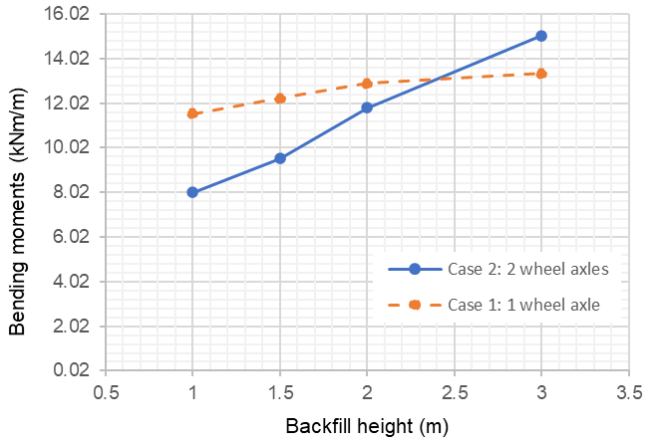


Figure 12*. Relationship between bending moments and thickness of backfill*

Table 5. *Result of this study*

No.	Results	Units	Backfill height (m)			
			1	1.5	2	3
1	**Case of 1 wheel axle load**					
	Total displacements	m	0.03341	0.03515	0.03763	0.04271
	Bending moments	kNm/m	11.55	12.24	12.92	13.36
2	**Case of 2-wheel axles load**					
	Total displacements	m	0.03361	0.03593	0.03962	0.04830
	Bending moments	kNm/m	8.02	9.54	11.82	15.05

For the total displacement, the analysis results in Table 5 shown that the displacement value of steel pipe increases according to the thickness of the embankment layer, which is true because of increasing load on corrugated pipe. Therefore, with a large thickness of the embankment layer, it is necessary to calculate and select a larger steel thickness. The total displacement value changes 11.5% in the case of placing 1 wheel axle with 2-wheel axles when the backfill height is 3m. But this value changes only 0.6%, 2.2% and 5.3% when the backfill height is 1m, 1.5m and 2.0m, respectively.

For the bending moment as shown in Fig. 12, bending moment value increases gradually with backfill height.

To consider the effect of stress, the 3D model is simulated with backfill height cases as described in section 3.1. The results in Fig. 14 shown that the maximum stress value for the case of backfill 3m is smaller than the allowable stress 330 MPa [1].

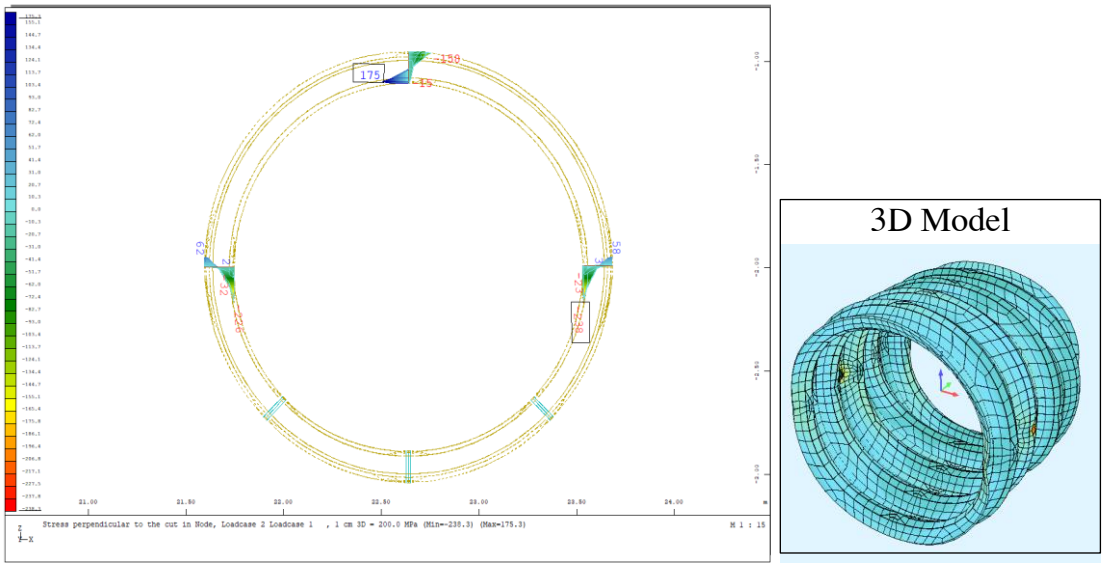


Figure 13. *3D model and the result of stress with backfill 3.0m*

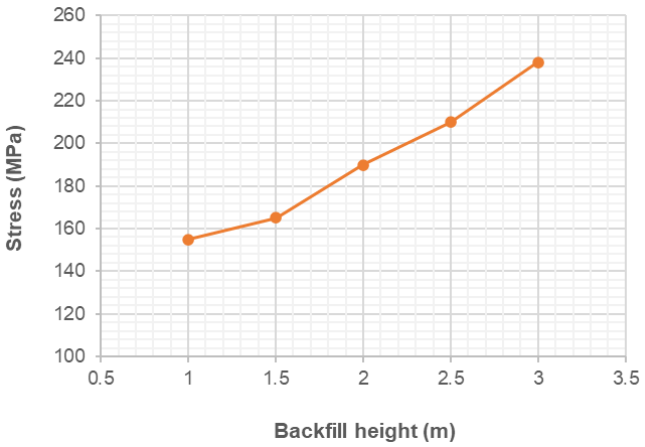


Figure 14. *Relationship between stress and thickness of backfill*

The total displacement of corrugated pipe depends on the vertical pressure of backfill soil on the structure. So, the difference of the bending moment and stress of corrugated pipe with vertical load is fairly large. Therefore, during the design, it is supposed to choose the corrugation pattern and thickness of the corrugated plate with a consideration of practical situation in order to optimizing design and saving construction cost.

IV. CONCLUSIONS

The corrugated steel culverts may be considered for underpass and sewerage on the highway under Vietnam conditions. Along with the simple design, construction is also convenient with thin steel plates that can be easily transported and assembled in the construction sites.

The results of conducted numerical analysis of corrugated steel pipe under the vertical loads shown the displacement values of the corrugated pipe is negligible, the stress values is less than the allowable stress of steel pipe, ensuring working conditions under the embankment from 1.0 to 3.0m in this study.

The steel corrugated culvert is suitable solution for rapid construction, so they need further research to be applied in practice.

ACKNOWLEDGMENT

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