International Journal of Scientific and Technical Research in Engineering (IJSTRE)
www.ijstre.com Volume 10 Issue 3 ‖ Nov-Dec 2025
ISSN: 2581-9941

Structural Validation of the Carrier for Four CNG Tanks on a Truck using the Finite Element Method (FEM)

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Abstract: The paper presents the structural validation of a carrier for four CNG tanks on trucks. The goal was to determine its reliability and structural integrity under critical conditions. The Finite Element Method (FEM) was used for modeling the carrier and conducting analyses according to defined criteria. The loads include forces defined in accordance with the technical requirements of the UN ECE Regulation R110. The FEM analysis resulted in precise values for the maximum stress and deformation of the structure. In conclusion, it has been proven that the existing carrier, with certain modifications, meets all prescribed safety standards, thereby confirming its structural integrity for further implementation and use in transport.

Keywords: *FEM (MKE), CNG Tank Carrier, UN ECE R110.*

I. Introduction

In accordance with increasingly stringent regulations on exhaust emissions, it is necessary to significantly reduce the emission of pollutants from internal combustion engines and simultaneously improve fuel economy to reduce CO_2 emissions from vehicles. Among the numerous technologies that contribute to global environmental protection and more efficient use of energy resources, natural gas stands out as an alternative fuel that simultaneously meets both of these requirements, so its increasingly widespread use is expected. [1]. Most of these vehicles use compressed natural gas (CNG) tanks [2].
The CNG tank carrier is designed to safely fix the fuel tanks to the vehicle. To ensure a sufficient range of movement, a set of four tanks is usually installed on trucks. The key engineering challenge is reflected in the design of the carrier (cradle/bracket) which must ensure the optimal combination of strength, mass, and reliability. The goal of this analysis is the application of the Finite Element Method (FEM) as a superior method compared to traditional calculations, which allows for precise simulation of static and dynamic loads—including extreme inertial forces during braking and impact—acting on the carriers. Through iterative optimization of the structure, the aim is to reduce the mass of the carrier while maintaining the required factor of safety (FOS). In this way, FEM analysis enables reliable validation of the strength and safety of this vital vehicle part under all operating conditions.

II. Methodology

In this paper, an analysis of the existing CNG tank carrier was performed using the **Finite Element Method (FEM)** in the SolidWorks software package, according to the loads defined in the UN ECE Regulation R110 [3].

According to UN ECE Regulation R110, CNG tanks must be mounted on the vehicle such that no damage occurs at the accelerations specified in Table 1, and the test is performed with maximally filled tanks.

Table 1.[3]

Vehicle category	Longitudinal Acceleration	Transverse Acceleration
M1 and N1	20g	8g
M2 and N2	10 g	5g
M3 and N3	6,6g	5g

In this case, the existing carrier (Proposal 1) is mounted on an N3 category vehicle (Figure 1.), so it follows that the critical accelerations are **6.6g in the longitudinal direction** and **5g in the transverse direction**.

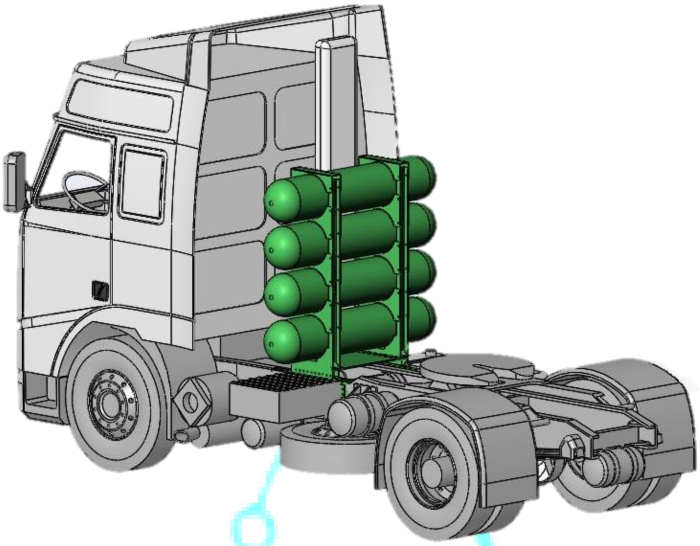

Figure 1. Position of the CNG tank carrier on the vehicle

Given data:

1. Test Object: Methane Tank Carrier
2. Specified Load in the Longitudinal Direction (Acceleration): $a_{pod} = 6,6[g]$ [3]
3. Specified Load in the Transverse Direction (Acceleration): $a_{pop} = 5[g]$ [3]

1. FEM Analysis of the CNG Tank Carrier – Proposal 1

1.1 Model of the CNG Tank Carrier – Proposal 1

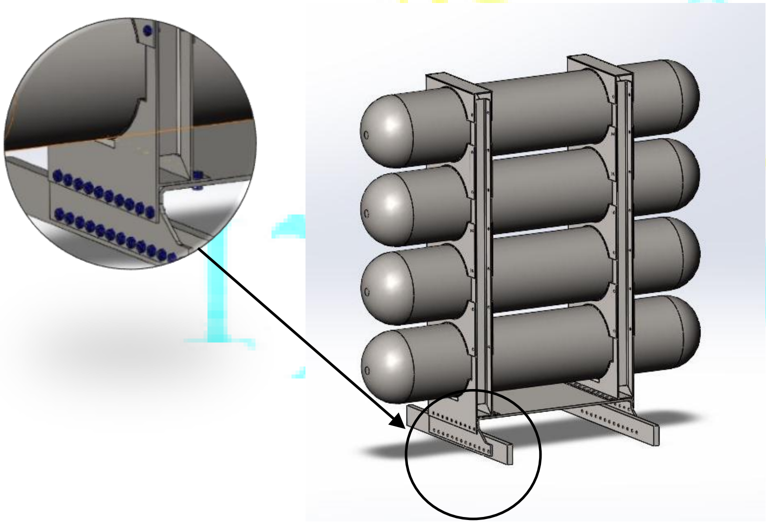

Figure 2. CNG Tank Carrier - Proposal 1

The mass of the CNG tank carrier together with the filled tanks is **824.5 kg**. This tank carrier is mounted on an **N3 category** vehicle, i.e., a tractor unit (truck).

1.2 Mesh on the Model – Proposal 1

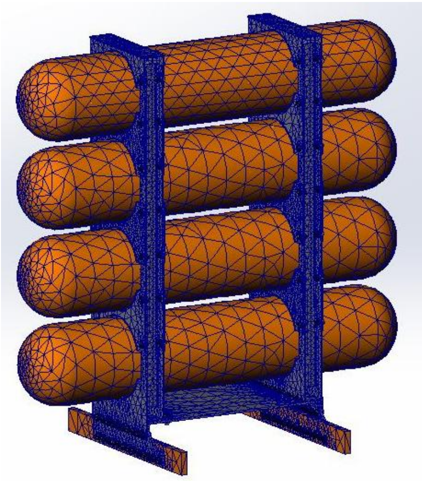

Figure 3. Mesh used for FEM on the CNG tank carrier – Proposal 1

Mesh data:

No. of elements =75746
No. of nodes = 158298

III. Boundary Conditions and Load Cases

For the purpose of conducting the FEM analysis, the model was partially simplified. The tanks were modeled as rigid bodies and replaced by rigid connections between the carriers, considering that in the directions of load action they exhibit significantly greater stiffness compared to the carrier itself. However, their mass has a significant impact on the total load of the structure, so it was not neglected in the calculation. The vehicle chassis was treated as an ideally rigid structure to simplify the calculation.

The CNG tank carrier is connected to the chassis using M14 bolts of quality 10.9, which is fully defined within the FEM model. The contact surfaces between the carrier and the tanks were modeled as rigid connections, in accordance with the previously stated assumptions about the stiffness of the tanks.

Two load cases are considered:

1. **Longitudinal Load:** 6.6 g – the mass of the tanks is multiplied by a factor of 6.6, and the force acts at the center of gravity of all four tanks in the longitudinal direction [3].
2. **Transverse Load:** 5 g – the mass of the tanks is multiplied by a factor of 5, and the force acts at the center of gravity of all four tanks in the transverse direction [3].

2. Results and Explanations of the FEM Analysis

1. Stress State during the First Load Case – 6.6g in the Longitudinal Direction (Proposal 1)

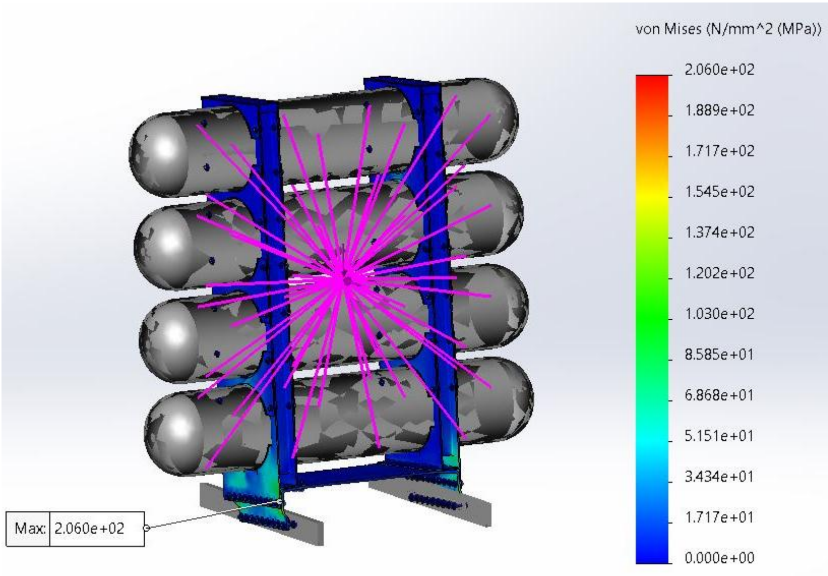

Figure 4. Stress state in the CNG tank carrier – Proposal 1 under a longitudinal load of 6.6g

As shown in Figure 4., the maximum stress is **206 MPa**.

2. Condition of the Bolt Connections during the First Load Case – 6.6g in the Longitudinal Direction (Proposal 1)

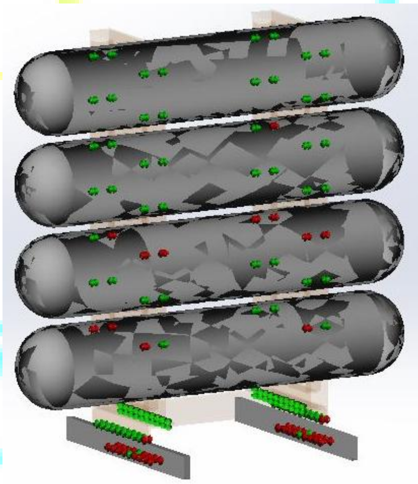

Figure 5. Condition of the bolt connections on the CNG tank carrier – Proposal 1 under a longitudinal load of 6.6g

The analysis results (Figure 5.) show that a significant number of bolts, marked in red, have a safety factor of less than 1 under the specified load. This indicates that the mentioned bolts would leave the elastic behavior range of the material, which would mean the requirement of the UN ECE Regulation R110 would not be met. *[3]*.

3. Stress State during the Second Load Case – 5g in the Transverse Direction (Proposal 1)

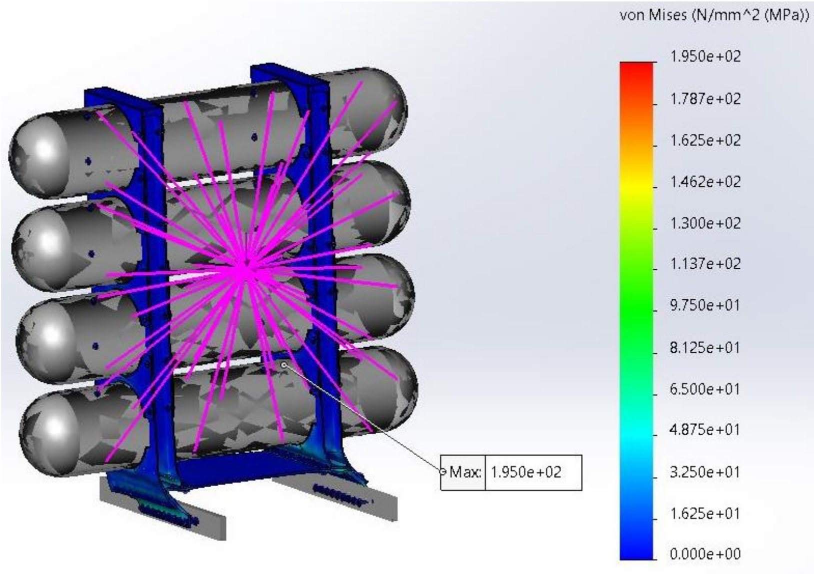

Figure 6. Stress state in the CNG tank carrier – Proposal 1 under a transverse load of 5g

As shown in Figure 6., the maximum stress value is **195 MPa**.

4. Condition of the Bolt Connections during the Second Load Case – 5g in the Transverse Direction (Proposal 1)

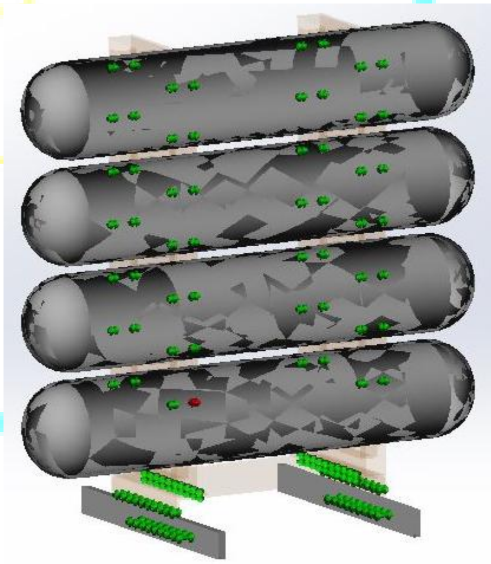

Figure 7. Condition of the bolt connections on the CNG tank carrier – Proposal 1 under a transverse load of 5g

In this case, the most critical bolt, marked in red, has a **safety factor of 1.99**, indicating that it is within the elastic range of the material.

3. FEM Analysis of the CNG Tank Carrier – Proposal 2

6.1 Model of the CNG Tank Carrier – Proposal 2

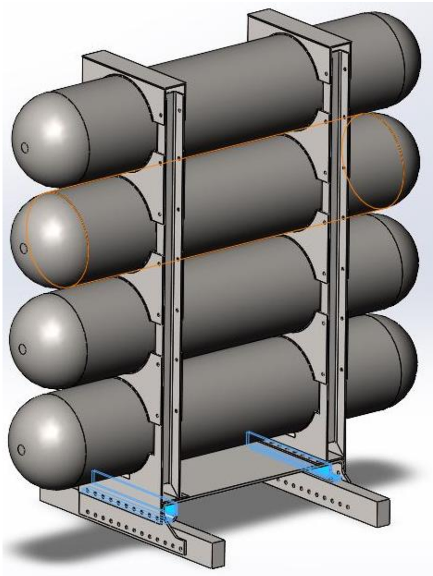

Figure 8. CNG Tank Carrier – Proposal 2

To comply with the requirements of the UN ECE Regulation R110, certain modifications were made to the carrier structure. An **L-profile** was added, which is connected to the existing carrier by welding and rests on the vehicle chassis to which the structure is mounted. The L-profiles are shown in Figure 8. and are marked in blue. The mass of the complete CNG tank carrier assembly with filled tanks is slightly changed and now amounts to 835.5 kg.

6.2 Mesh on the Model – Proposal 2

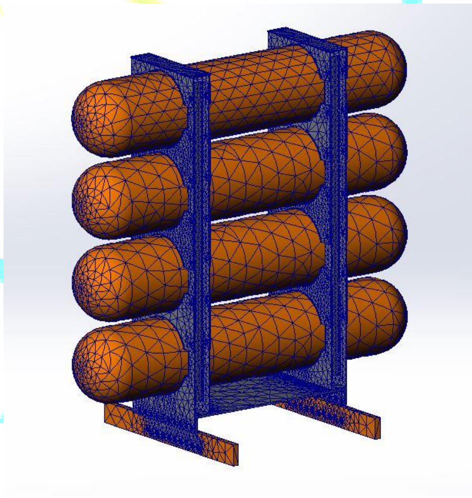

Figure 9. Mesh used for FEM on the CNG tank carrier – Proposal 2

Mesh data:

No. of elements =79133
No. of nodes = 164904

6.3 Boundary Conditions and Load Cases

The boundary conditions and loads are the same as for Proposal 1.

6.4 Results and Explanations of the FEM Analysis

1. Stress State during the First Load Case – 6.6g in the Longitudinal Direction (Proposal 2)

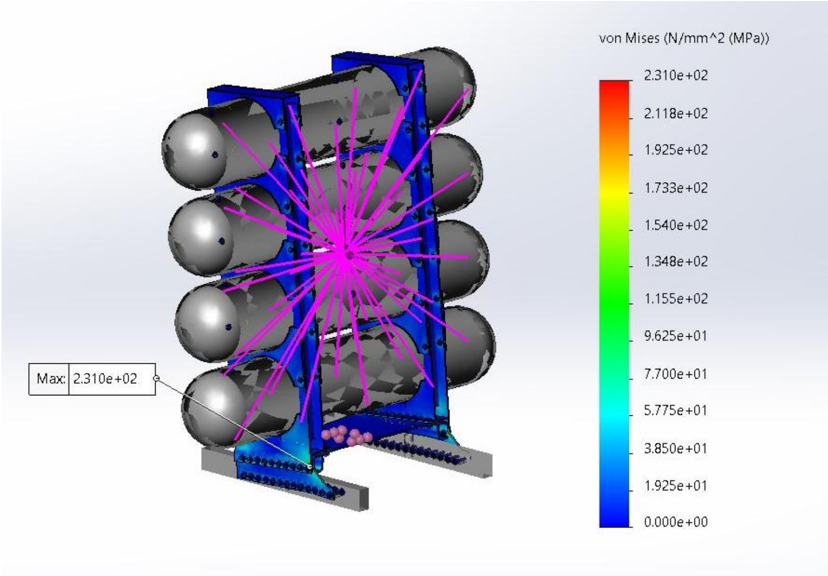

Figure 10. Stress state in the CNG tank carrier – Proposal 2 under a longitudinal load of 6.6g

As shown in Figure 10., the maximum stress is 231 MPa.

2. Condition of the Bolt Connections during the First Load Case – 6.6g in the Longitudinal Direction (Proposal 2)

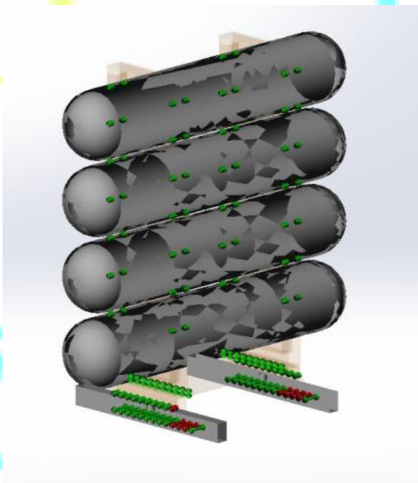

Figure 11. Condition of the bolt connections on the CNG tank carrier – Proposal 2 under a longitudinal load of 6.6g

Figure 11. shows multiple critical bolt connections. All bolt connections marked in red have a safety factor in the range of 1.88 to 1.98, indicating that they are within the elastic deformation range of the material.

3. Stress State during the Second Load Case – 5g in the Transverse Direction (Proposal 2)

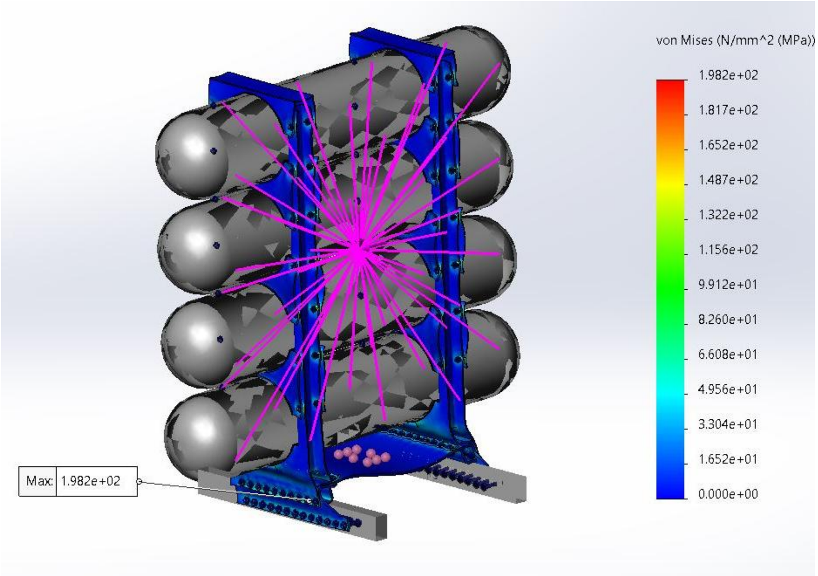

Figure 12. Stress state in the CNG tank carrier – Proposal 2 under a transverse load of 5g

As shown in Figure 12., the maximum stress is 198.2 MPa.

<u>4. Condition of the Bolt Connections during the Second Load Case – 5g in the Transverse Direction (Proposal 2)</u>

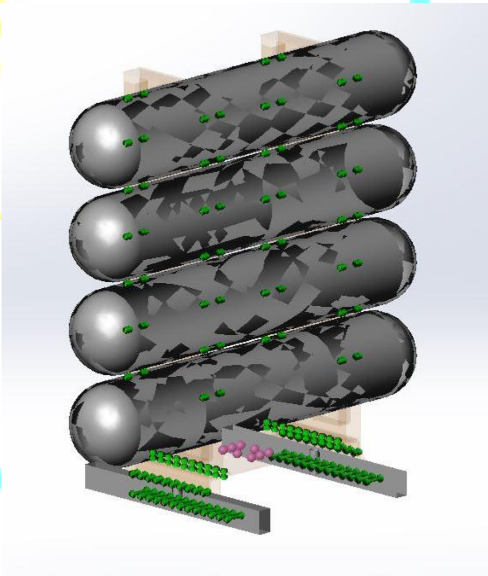

Figure 13. Condition of the bolt connections on the CNG tank carrier – Proposal 2 under a transverse load of 5g

In this case, it is observed that all bolts can withstand the specified load..

To ensure the structure meets all relevant conditions, it is necessary to select an appropriate material given the maximum operating stress of 231 MPa. For the given conditions, a possible choice is S235 steel, whose characteristics are shown in Table 2. However, since the maximum operating stress is very close to the yield strength of this material, the use of **S355 steel** is recommended, whose characteristics are also shown in Table 2.

Table 2[4]

Material Density	S235	S355
Gustina materijala ρ	7850 kg/m^3	

Modulus of Elasticity (Young's Modulus) E	210000 *MPa*	
Shear Modulus (G)	$G=E/[2(1+\nu)] \approx 81000$ *MPa*	
Poisson's Ratio (ν)	0,3	
Yield Strength R_e	235 *MPa*	355 *MPa*
Tensile Strength R_m	360 *MPa*	490 *MPa*

Comparative Table of Results for the Observed Carriers

Table 3		
Uslovi opterećenja	Proposal 1	Proposal 2
Stress state $[MPa]$ at longitudinal deceleration 6.6g	206	231
Stress state $[MPa]$ at transverse deceleration 5g	195	198.2

By comparing the results shown in Table 3, it can be concluded that Proposal 1 is more favorable from the aspect of lower operating stresses in the material. However, in addition to material stress, a significant factor is the bolt connections, which are in a much more favorable situation with Proposal 2, i.e., no bolt is outside the elastic range of the material. Therefore, from the standpoint of overall functionality and safety, Proposal 2 is considered more suitable for use.

IV. Conclusion

Based on the conducted analysis of the new carrier for four CNG tanks on trucks using the Finite Element Method (FEM), the structural integrity of the structure has been confirmed in accordance with the requirements of the UN ECE Regulation R110. The carrier was subjected to critical loads of 6.6g in the longitudinal direction and 5g in the transverse direction [3].

The key findings of the comparative analysis of the two proposals are as follows:

1. **Proposal 1** showed shortcomings in the safety of the bolt connections, with a significant number of bolts being outside the elastic deformation range.
2. **Proposal 2** proved to be a more reliable solution, as all bolt connections remained within the elastic deformation range in all simulated load conditions (6.6g longitudinal and 5g transverse), although the stress state in the material is marginally less favorable.

Given that Proposal 2 meets all prescribed safety standards, it is recommended for further implementation and use in transport. For the carrier structure (Proposal 2) to satisfy the condition at a maximum stress of 231 MPa, it is necessary to use a material with a yield strength greater than 235 MPa. The selection of S355 steel is recommended.

V. References

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