Modeling the *In Situ* Performance of Culvert Joints in a Pavement Structure

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Abstract:

The Saskatchewan Ministry of Highways and Infrastructure (MHI) is responsible for approximately 65,000 culverts. Under typical field state conditions, corrugated steel pipe (CSP) culverts have a design life of approximately 30 years. These culverts can pull apart at the joints due to the level of friction between the culvert and surrounding soil, causing the culvert and ultimately the road to fail. This study employed a computational road model to investigate the strain behaviour along the culvert-road soil interface and to examine the mechanisms by which culvert joints pull apart. Two pavement structures were modeled in two different moisture conditions: a primary and secondary road structure, in both wet and dry moisture states. The secondary road structure in a wet moisture condition state had overall higher magnitudes of shear and horizontal strains compared to the other road structures and condition states. From a dry to wet moisture condition state on the secondary road, shear strain increased by 119%, the horizontal strain in the longitudinal direction increased by 114%, and the horizontal strain in the transverse direction increased by 116%. This research showed that the horizontal strain in the longitudinal direction was greater in magnitude for the wet moisture condition states in comparison to the dry moisture condition states. Improved mechanistic modeling of culverts in diverse field state conditions could significantly assist road engineers to better design culvert installations. Accurately modeling and diagnosing culverts non-destructively could also help identify early signs of structural failure, which would enable road agencies to implement a proactive methodology for culvert remediation.

Background:

- The majority of Saskatchewan's rural in-service culverts are corrugated steel pipe (CSP), and some are reinforced concrete pipe (RCP).
- CSP culverts have a design life of approximately 30 years.
- Besides plugging and/or washing out, culvert performance deterioration can be the result of many factors:
    - Temperature effects can accelerate CSP culvert corrosion.
    - Reduced invert strength can cause a culvert to scour and fail.
    - Joint separation.
    - Cavitation.
    - Reduced depth of cover.
- Traditional culvert remediation and in-service culvert replacement methods include:
    - Full depth excavation and replacement.
    - Ram jacking steel pipe outside or inside existing pipe.
    - Boring/tunneling a new culvert.
- Traditional methods of culvert rehabilitation can be inconvenient, as they involve significant time and cost, as well as delays to traffic.
- The ability to accurately diagnose culverts non-destructively in order to identify early signs of pipe structural failure would enable road agencies to implement a proactive methodology for culvert remediation.

Mechanism of Joint Separation

- Climatic effects:
    - During freeze-thaw cycles, water can seep into culvert joints and freeze, causing joint separation.
    - When soil freezes, clay soils can swell and cause up-heaving as well as shear along the pipe.
    - Saskatchewan has silty and clayey subgrades subject to moisture issues and swelling.
- Culvert joints can pull apart due to differential settling in the surrounding soil.
    - As soil settles, loosens, or erodes around the culvert pipe, the fill material loses its lateral structural support capacity which alters the structural properties of the culvert and soil system.
    - Voids in the surrounding soil are created and pressures around the pipe are altered.
- It is hypothesized that tensile forces in the surrounding soil are reduced and result in culvert joints separating, or being pulled apart.

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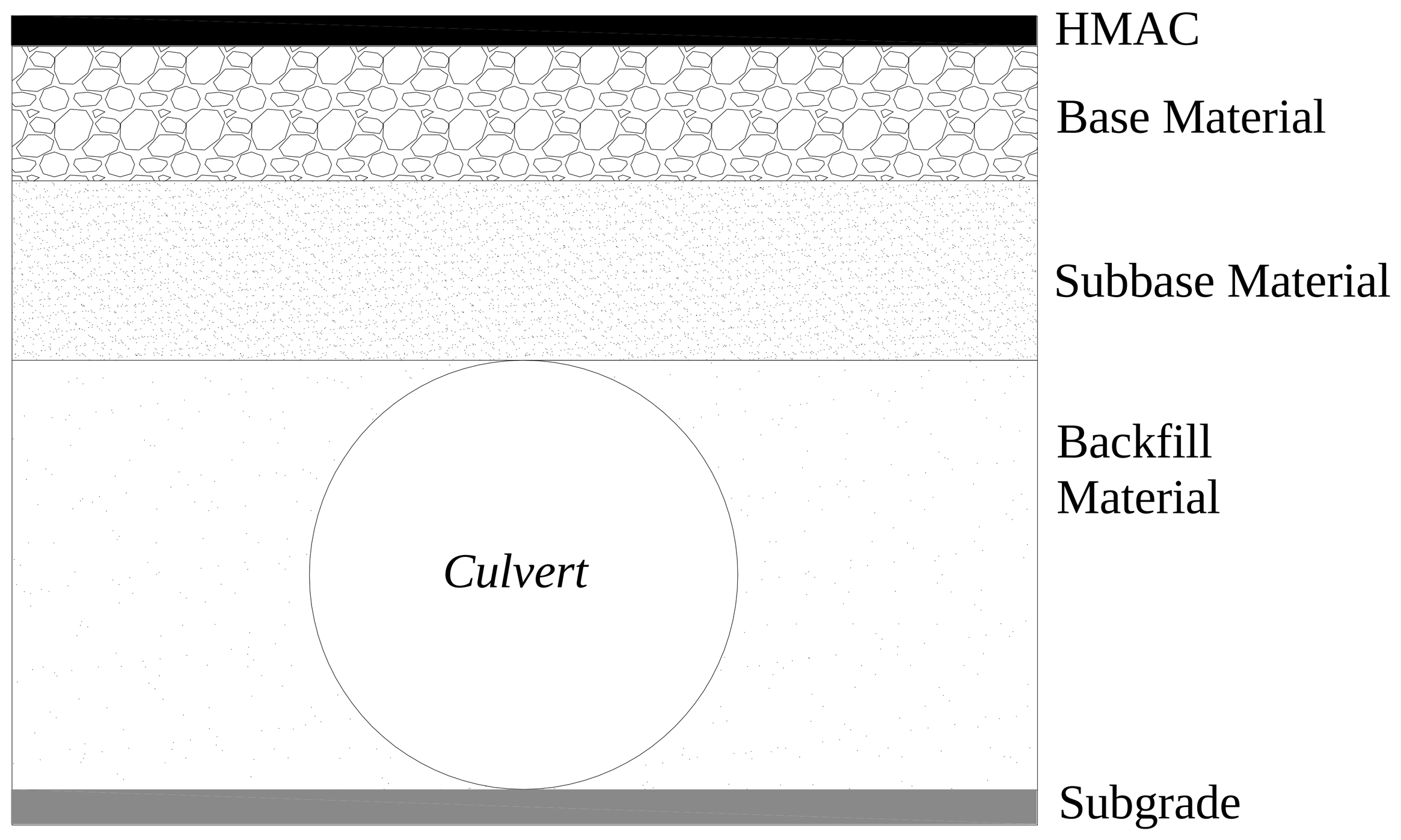
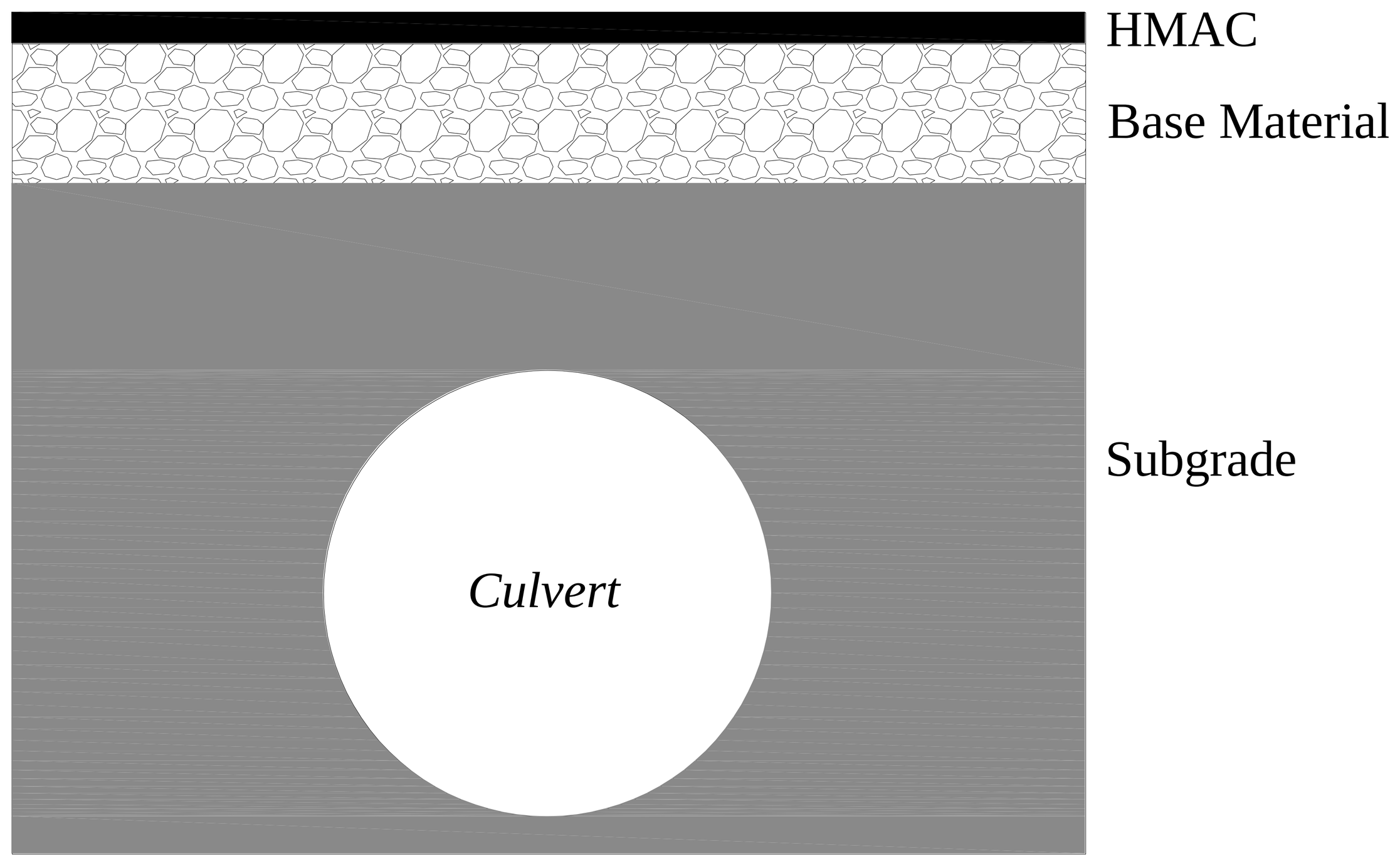
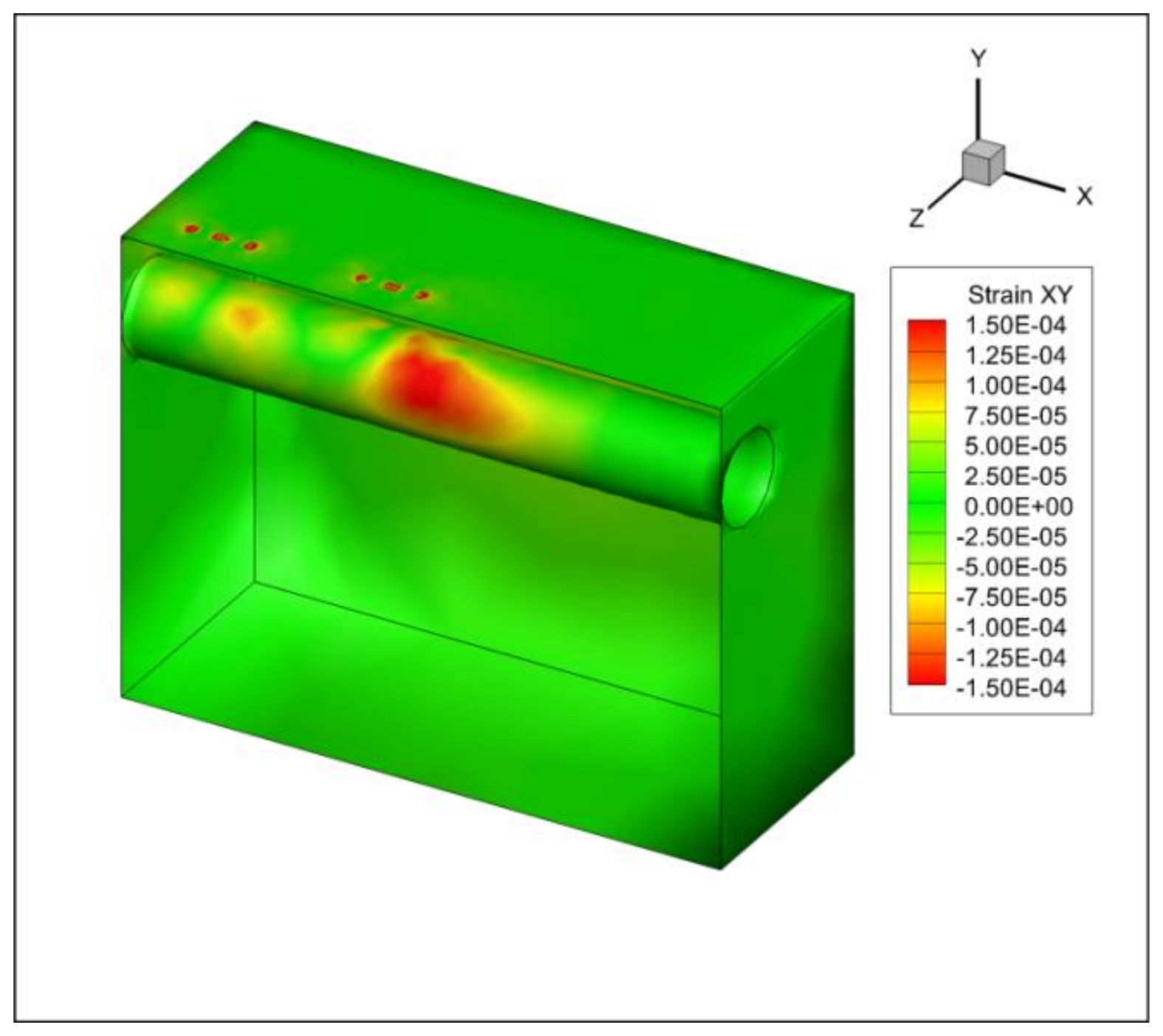
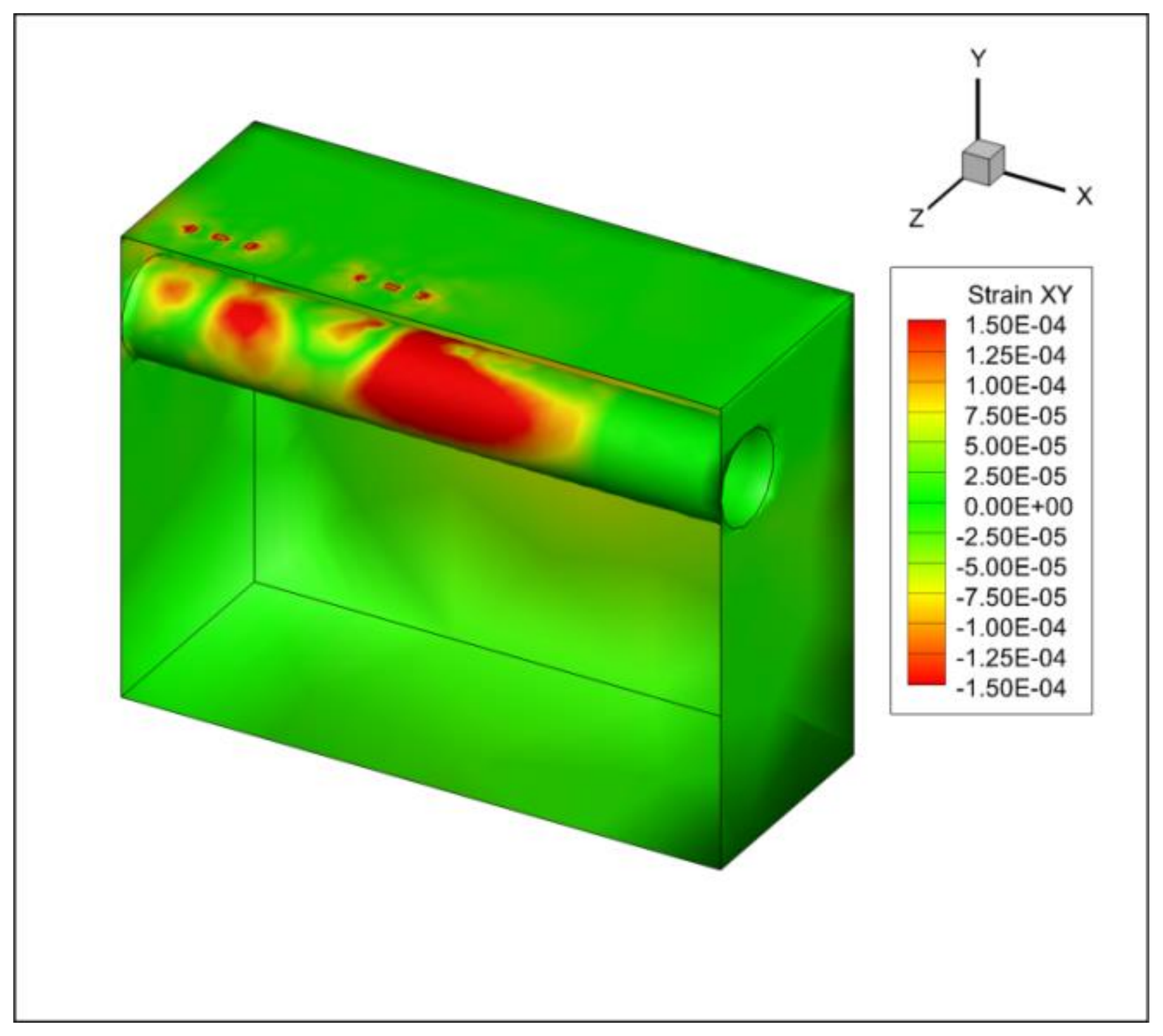
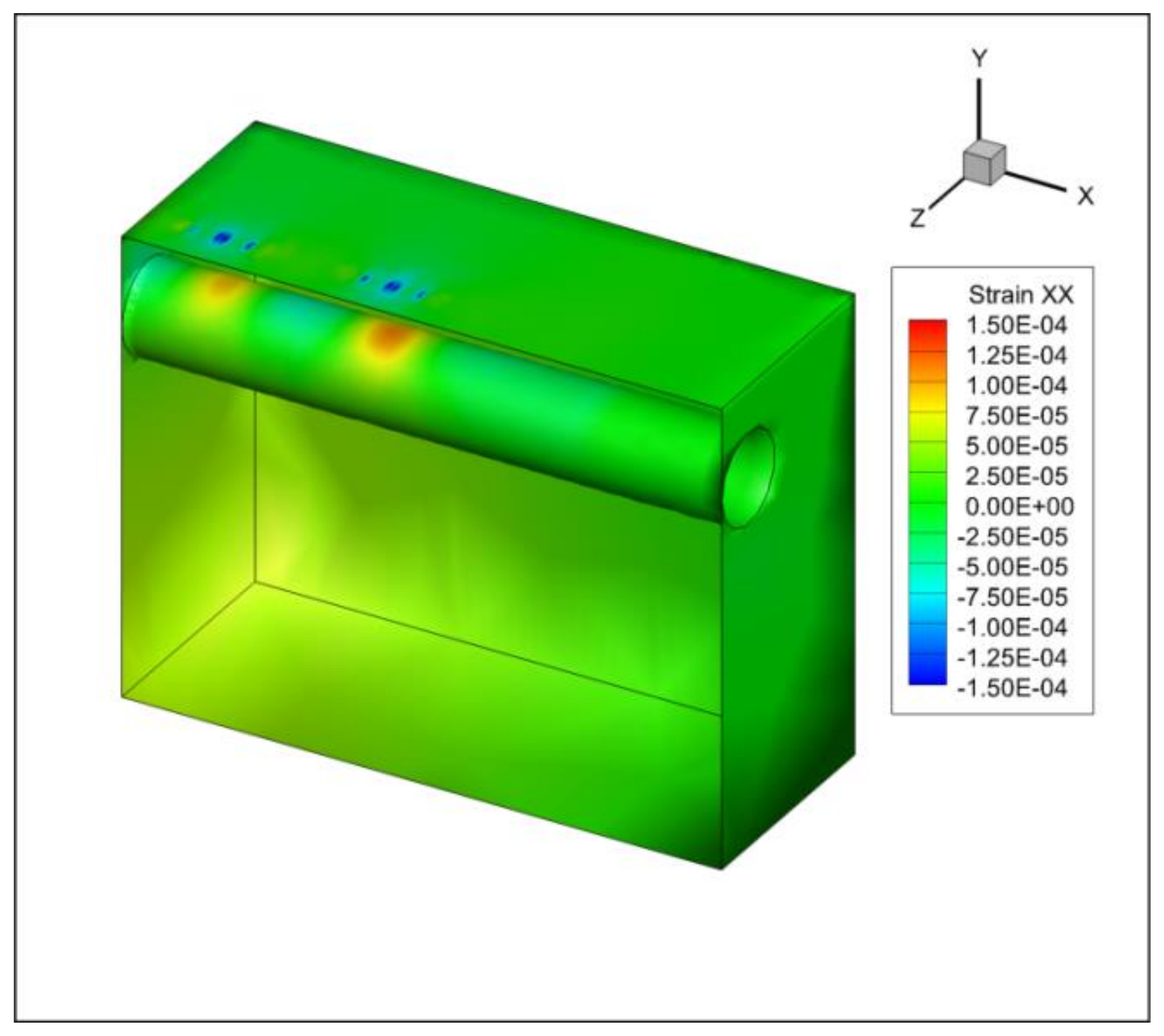
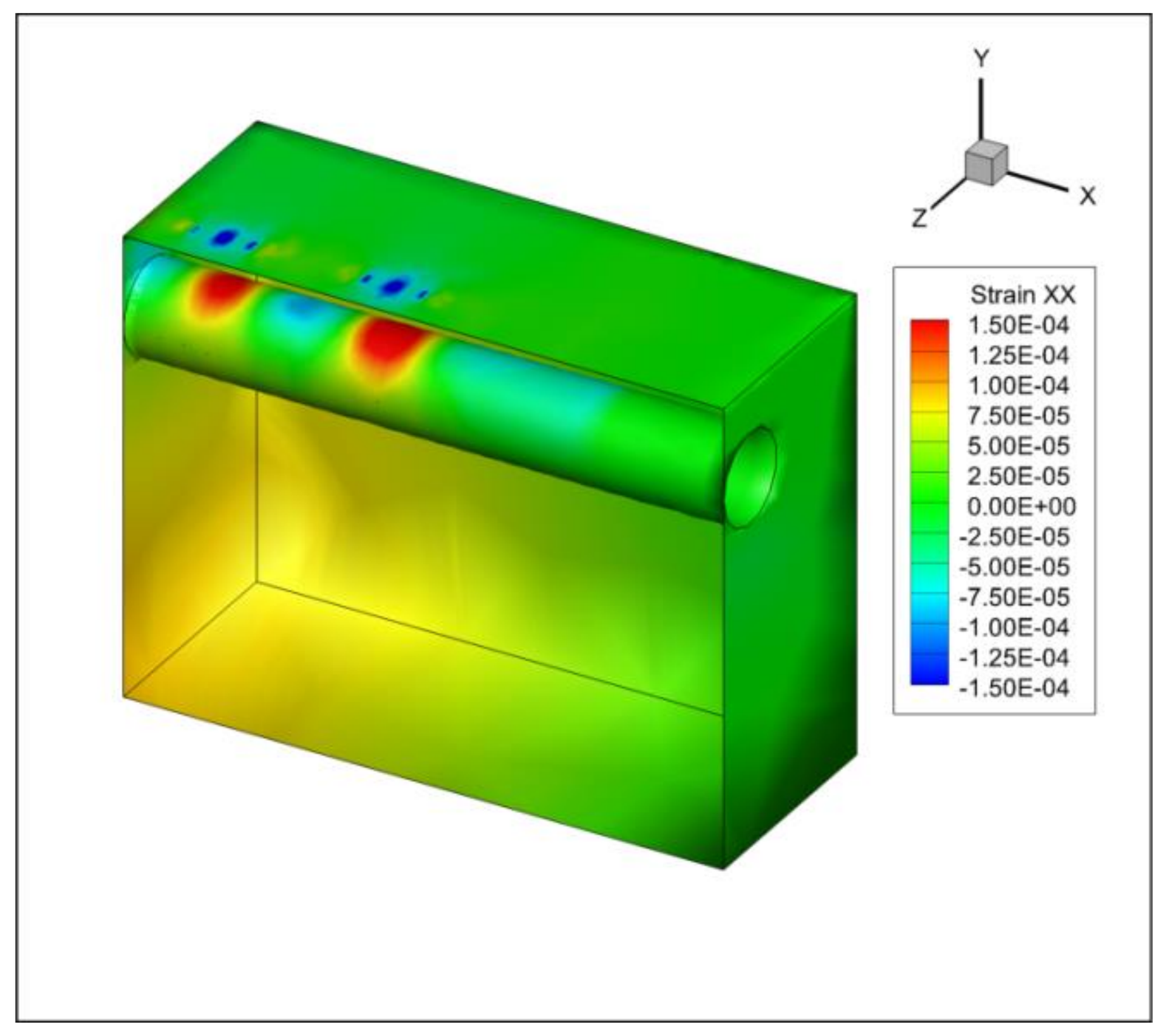
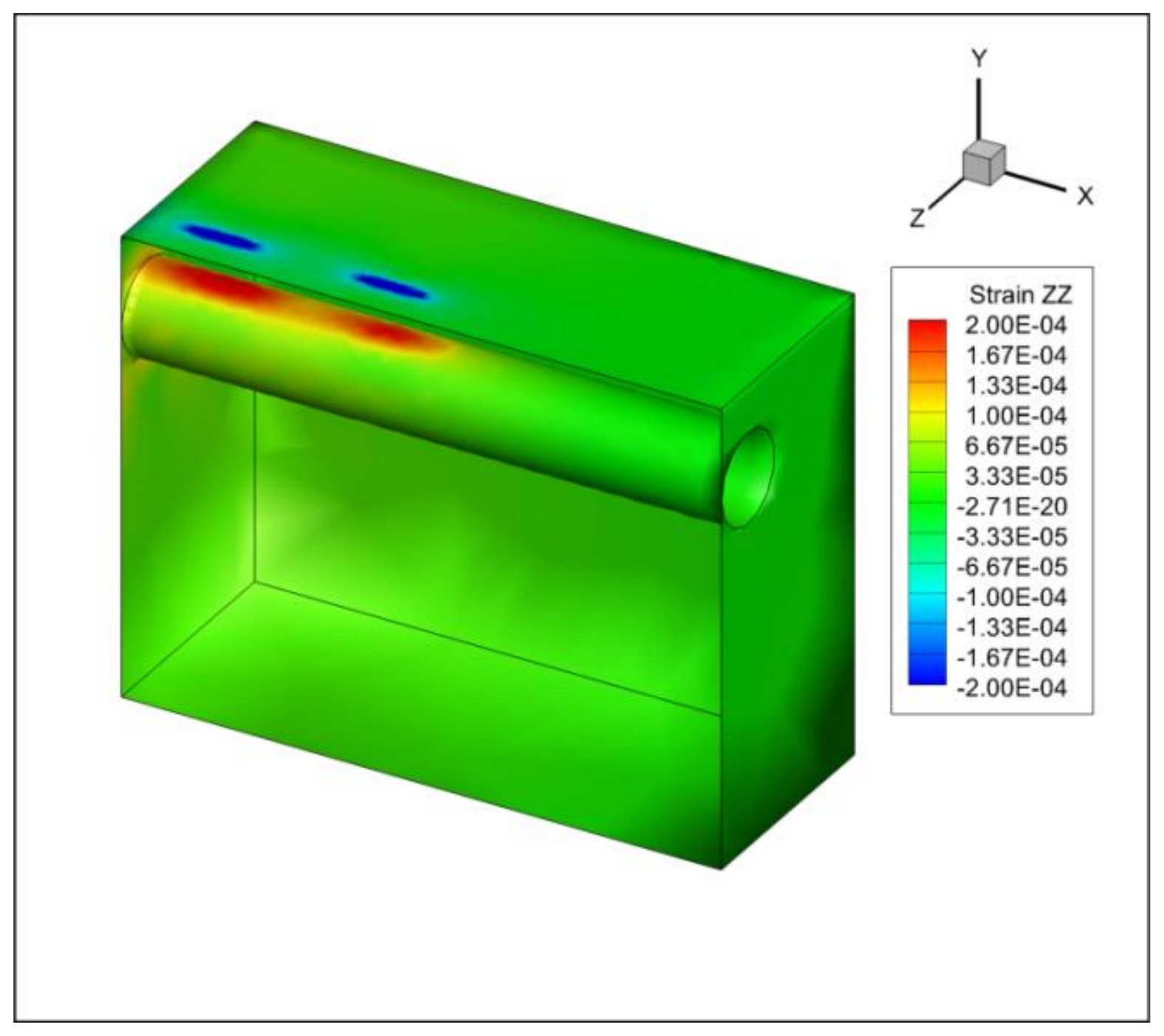
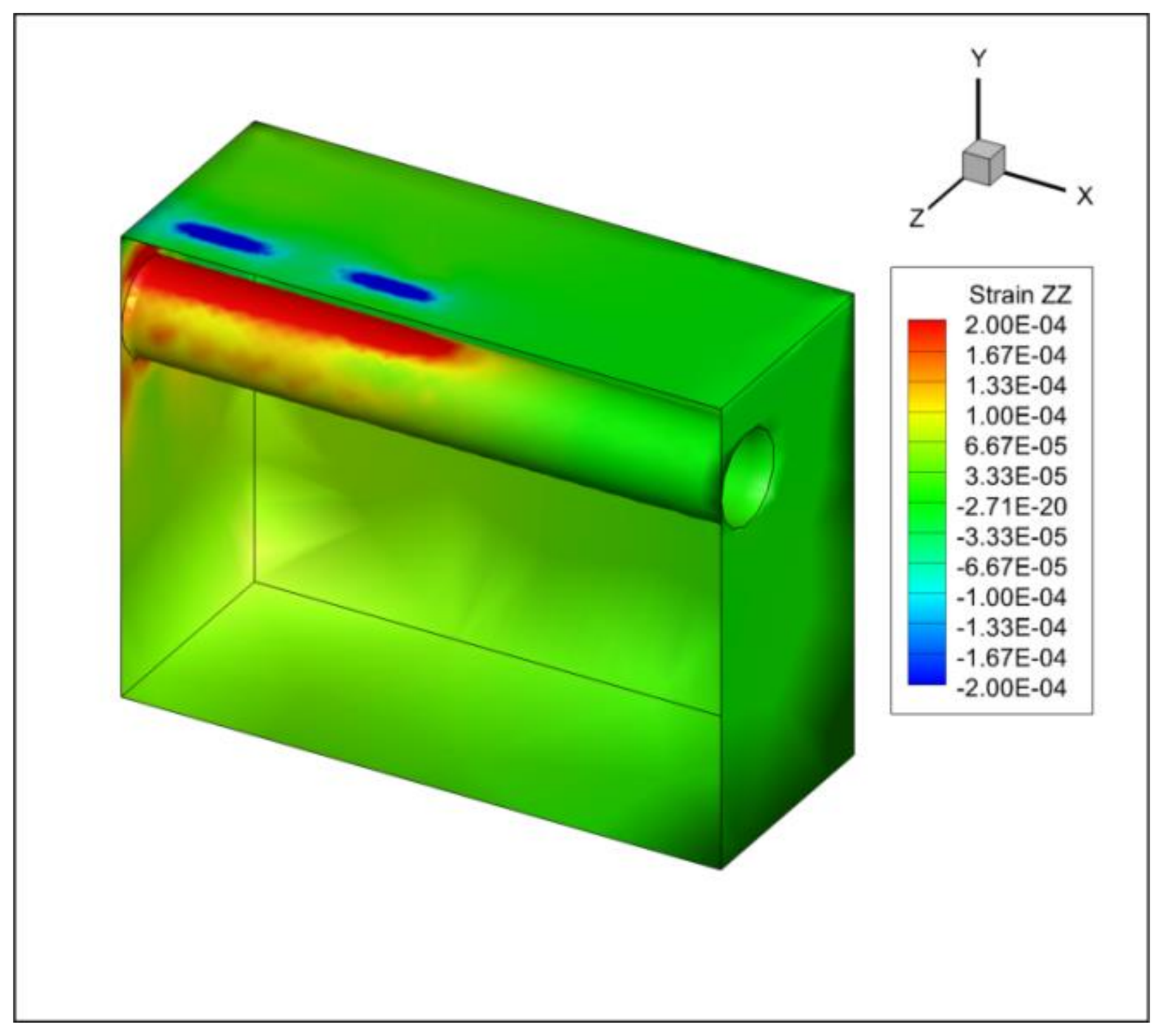
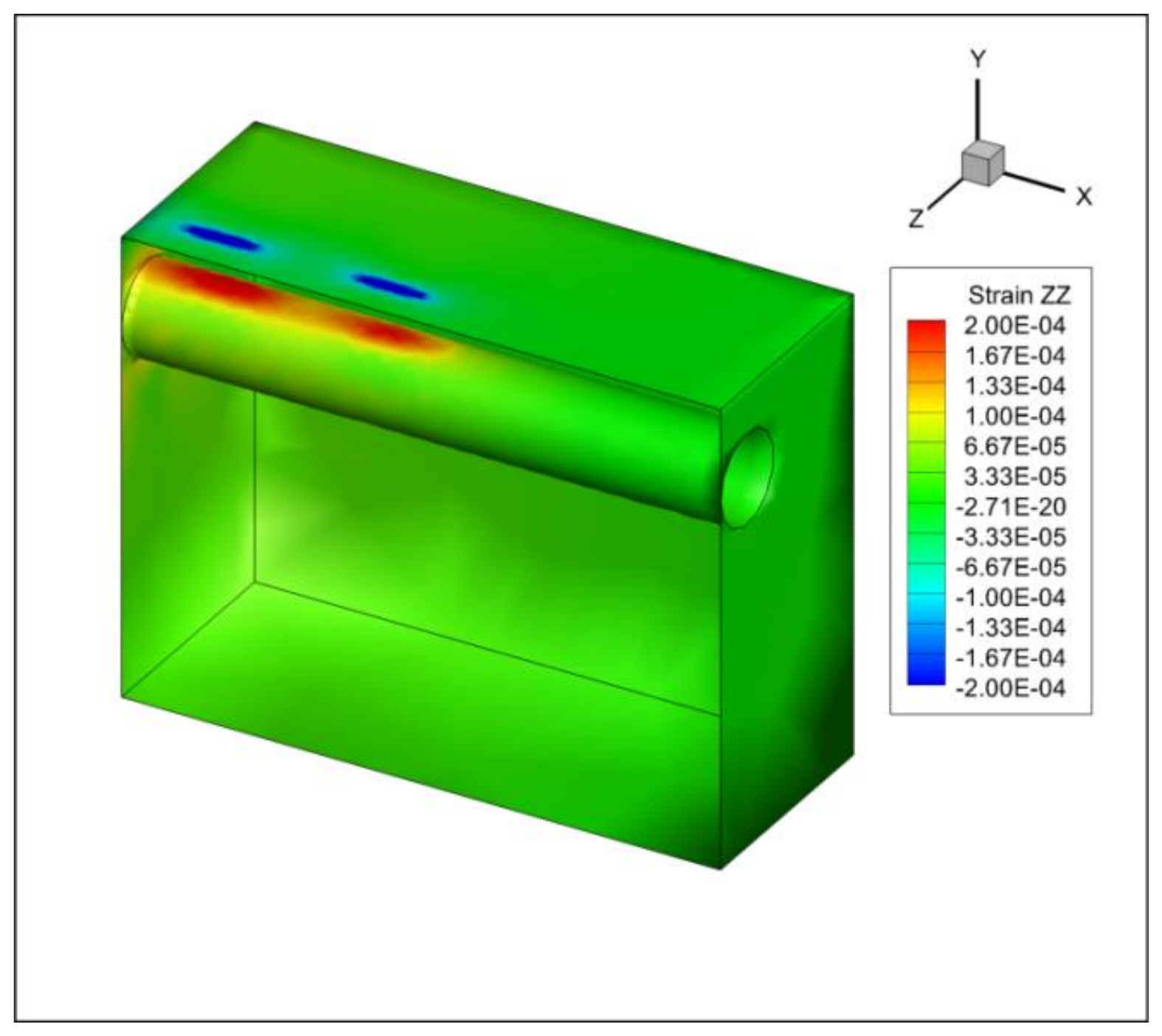
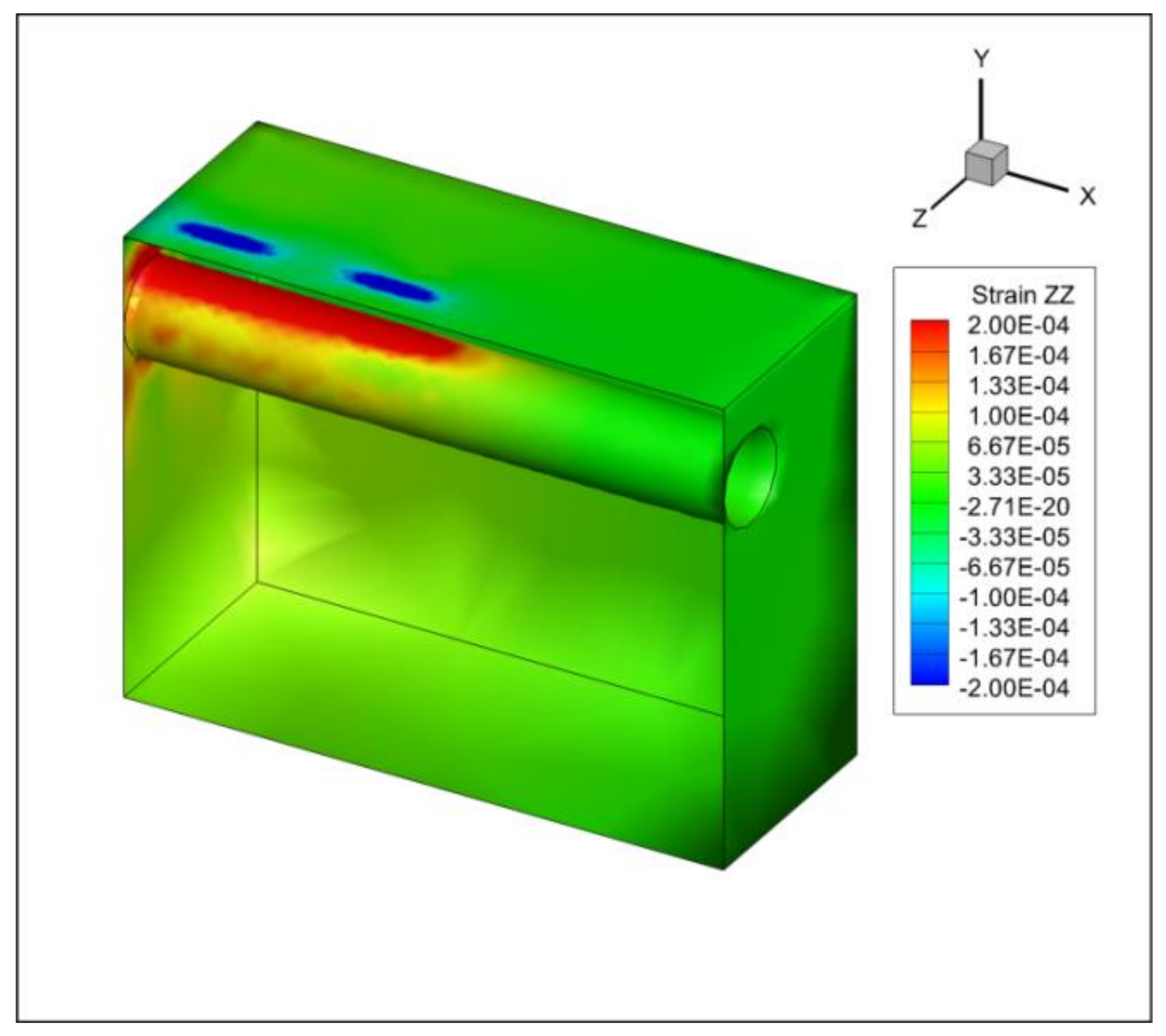
Network Level Surface and Structural Assessment:

	Primary Road Structure with CSP Culvert		Secondary Road Structure with CSP Culvert	
Cross Section				
	Modeling Results			
	Dry Condition State	**Wet Condition State**	**Dry Condition State**	**Wet Condition State**
Shear Strain				
Horizontal Strain in the Transverse Direction				

Conclusions:

- The modeled strain states concur with observed field performance and observed failure of culverts in the field.
  - A culvert can be pulled apart at the joint depending on its' *in situ* condition, including a weakened horizontal strain state in the transverse direction and poor sub-surface material surrounding the culvert.
  - Aged or corroded material along with earth movement around the pipe and heavy cyclic loads can induce movements around the joints and cause it to pull apart.
- By modeling the culvert and road structure performance, the condition state of *in situ* culverts in the field can be better determined to identify early signs of pipe structural failure.
- Modeling culverts in varying soil conditions may improve installation protocols.
- For the primary road structure, from a dry to wet moisture condition state:
  - The shear strain increased by 245%;
  - The horizontal strain in the longitudinal direction increased by 93%; and
  - The horizontal strain in the transverse direction increased by 90%
- For the secondary road structure, from a dry to wet moisture condition state:
  - The shear strain increased by 119%;
  - The horizontal strain in the longitudinal direction increased by 114%; and
  - The horizontal strain in the transverse direction increased by 116%.
- The secondary road structure had higher strains compared to the primary road structure in both dry and wet moisture condition states.
  - The shear strains are greater in the secondary road structure because there is no subbase or backfill material surrounding the culvert.
- Overall, the secondary road structure with a wet moisture condition state had overall higher magnitudes of shear and horizontal strains compared to the other road structures and condition states.