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## A Novel Approach in Protecting Steel Pipelines against Explosions Using FRP

Mohammad Tabiee<sup>1</sup>, Alireza Khaloo<sup>2\*</sup>

<sup>1</sup> Ph.D. student of department of civil engineering, Sharif University of Technology, Tehran, Iran.

<sup>2</sup> Professor of department of civil engineering, Sharif University of Technology, Tehran, Iran.

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### 1. ABSTRACT

The expansion of pipeline transmission networks has increasingly highlighted the importance of protecting them against hazards, particularly blasts. The application of Fiber Reinforced Polymers (FRP) is one of the most suitable approaches to achieving this objective. This study presents the analytical relationships governing the behavior of FRP-reinforced pipelines under blasts, evaluating the protective effectiveness of FRP in steel pipelines under various conditions through the analysis of a case study. The results demonstrate that the application of Carbon Fiber Reinforced Polymers (CFRP) can be particularly effective for protecting thin-walled pipes with shallow burial depths in hard soils, which are more vulnerable to blasts. Furthermore, FRP material thickness significantly impacts the resistance of the pipelines to blasts. In certain cases, adopting an appropriate value can enhance the pipeline blast resistance more than 2.5 times compared to the initial value.

**Keywords:** Pipeline, FRP, Composite Materials, Reinforcement, Blast Loading.

### INTRODUCTION

Pipelines are used for the transportation of gases and liquids like oil products, water, and sewage, and therefore the structural integrity of pipelines is of strategic concern globally. Since pipelines are used extensively and play an important role, they are exposed to various hazards and may suffer various forms of damage during their service lifetime. The first threat is the effect of the explosive loading on the structure of the pipeline. Explosive loading can be due to military operations, terrorists or subversive activities, construction work, blast drilling, or pipe failure due to some defects or due to wear and tear [1].

In recent decades, the use of fiber-reinforced polymers (FRPs) composite materials for structural reinforcement, particularly in pipelines, has gained significant popularity. This trend is due to the advantages FRPs offer over traditional methods [2-3]. The fibers commonly used in these composites include carbon (CFRP), glass (GFRP), aramid (AFRP), and basalt (BFRP). Previously, FRP materials were mostly used to restore worn or corroded parts and to strengthen seams and pipeline connections [2, 4-5]. However, studies in recent years have shown that they can be used to improve structural strength against unpredictable loads such as explosions.

The objective of this research is to analyze the effectiveness of FRP composites in reinforcing pipelines subjected to explosive loading. To achieve this, in this paper first introduces the governing relationships for pipelines reinforced with composite materials under such loading conditions. Following this, a parametric study is conducted, using a practical example to examine the key variables of the problem. This approach allows for an evaluation of the efficiency of FRP composites in enhancing pipeline resistance to explosions and the influence of other critical factors. Finally, the findings are discussed, with key summaries and conclusions provided.

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## 2. MATERIALS AND METHODS

Consider a pipeline with an outer diameter  $D_b$ , thickness  $t_b$ , and length  $L$ , which is reinforced with composite materials of thickness  $t_{FRP}$  and fiber coverage at an angle  $\theta_{FRP}$ .

Since pipelines are mostly underground structures that depend on the support of the surrounding soil, we assume that this pipeline is buried at a depth of  $h$  from the surface of the earth. An explosive charge is detonated at a distance  $r$  from the pipeline and the explosive load produced is  $q_D(x,t)$ . The fundamental components of the response of this FRP-reinforced pipeline to the explosive load can be calculated using the relationships provided in the appendix of the article and the procedure illustrated in Figure 1.

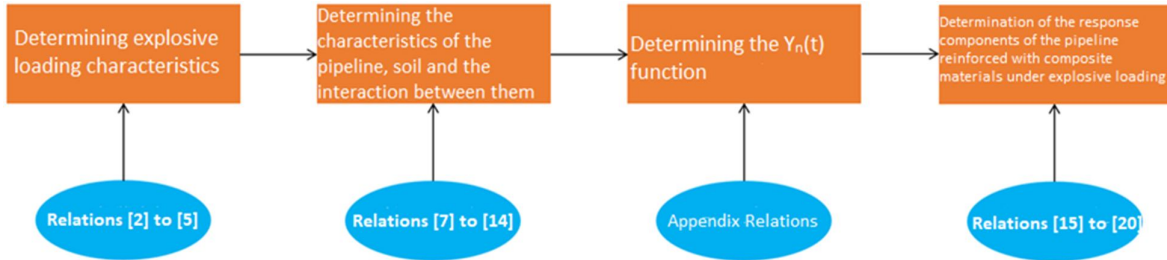


Figure 1. Procedure for determining the response of an FRP-reinforced pipeline under explosive loading.

In the subsequent sections, we apply this strategy to a practical example, evaluating the effectiveness of FRP composite materials in reinforcing pipelines subjected to explosive loading, and the impact of critical factors on the responses.

## RESULTS AND DISCUSSION

Suppose a pipeline has an external diameter of 168.30 mm, a thickness of 7.11 mm, and a length of 3 meters, and is buried 50 cm below the ground. This pipeline is reinforced along its length with CFRP fibers of 2.5 mm thickness. An explosive charge equal to 400 grams of TNT is placed on the ground right above the middle of the pipeline and is detonated, resulting in the shock waves traveling through the soil. In the next phase of the study, the effects of varying key parameters on the effectiveness of FRP materials in protecting the pipeline from explosive loading are assessed. The impact of each parameter on the pipeline's resistance to explosion is evaluated, with the results detailed in the text of the article. Figure 2 presents the data from a parametric study examining the influence of pipeline thickness on controlling maximum deformation and stress levels in the middle of the pipeline when reinforced with FRP also the key findings from this research are summarized in the following section.

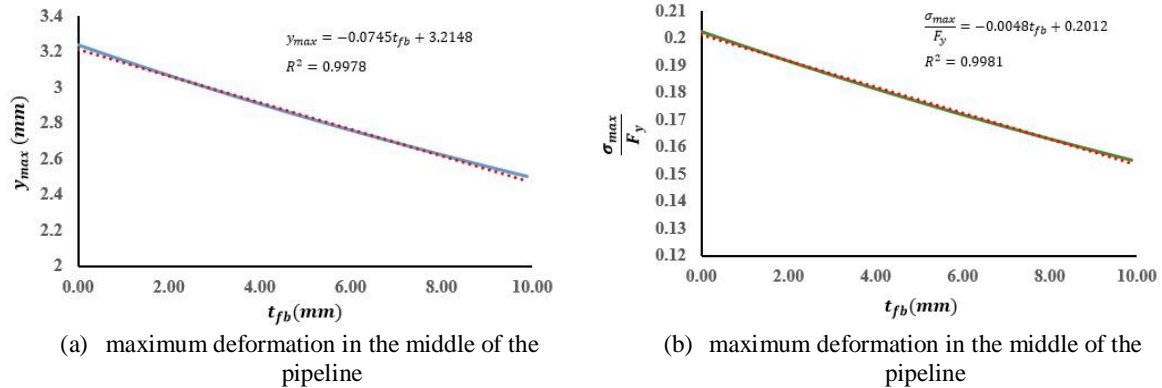


Figure 2. Analysis of the impact of pipeline thickness on the control of maximum deformation and stress in the pipeline's midpoint with FRP reinforcement.

## 3. CONCLUSION

This research aimed to evaluate the effectiveness of FRP composite materials in reinforcing and protecting steel pipelines against explosive loading. Additionally, it sought to provide the necessary analytical relationships for engineers and designers to facilitate preliminary design and analysis. The main findings and results from this study are summarized below.

- Among the various types of FRP fibers, carbon fibers (CFRP) are the most effective in controlling deformation and longitudinal stress, offering superior protection for pipelines against explosions due to their higher longitudinal hardness.



- Given the multilateral pressure exerted by an explosion, it is advisable to use FRP composite materials with bidirectional fibers where possible. If unidirectional fibers are used, aligning them along the pipeline's length is more effective.
- The thickness of the composite materials ( $t_{fp}$ ) is a critical factor in reinforcing and protecting pipelines from explosions. This parameter should be carefully considered during design, alongside other pipeline characteristics such as diameter, length, and economic aspects.
- The parametric study indicates that thin-walled pipelines, especially those buried at shallow depths in hard soil, are more vulnerable to explosive loading. In these conditions, FRP materials are particularly efficient, as even with a smaller thickness, they significantly reduce the deformation and stress caused by an explosion.

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