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Best Safety Practices for Stability of PVC Pipe Bundles During Transportation

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Abstract: This paper addresses industry's best safety practices for the loading, transportation, and unloading of polyvinyl chloride (PVC) plastic pipe bundles on flatbed trailers. A review of industry literature and standards identifies calculation methods to verify that the appropriate grade of strap is being used for the application, as well as a formula to determine the appropriate number of straps for the weight of the PVC pipe bundle based on the tensile break load strength of the strap and a safety factor to account for variations in material properties and loading conditions. Factors that affect the stability of PVC pipe bundles during transport include pipe stacking techniques, pipe loading and unloading methods, dunnage selection, number of pipe bundle straps used, strap welding methods and material properties, truck tie-down strap application, trailer load securement stakes, and inspection methods of the straps and load. Case studies associated with PVC pipe bundles that became unstable during transport and resulted in loss of the load during unloading are presented. Accident reconstruction analysis is utilized to assess and manage the risk associated with unstable PVC pipe bundles. Failure analysis of the polyester (PET) straps provides insight into the causation of PVC pipe bundle loss incidents.

Keywords: PVC Pipe Bundles, Stability, Transportation

1. Literature Review

U.S. Federal Motor Carrier Regulations provide requirements for inspection of commercial motor vehicle cargo, cargo securement devices, and cargo systems (FMCSA, 2022). In general, a driver may not operate a commercial motor vehicle and a motor carrier may not require or permit a driver to operate a commercial motor vehicle unless the commercial motor vehicle's cargo is properly distributed and adequately secured as specified in the Federal Motor Carrier Safety Administration (FMCSA) regulations. Performance Pipe, a division of Chevron Phillips Chemical Company and one of the largest producers of piping products in North America, developed a transport strapping policy that establishes minimum requirements regarding the number of truck tie-down straps used by transportation providers to secure pipe products and recommends locations for strap placement (Performance Pipe, 2011). This strapping policy for securing bundles and bulk packs to a flatbed trailer has a minimum requirement of six straps to secure one layer, eight straps to secure loads consisting of two, three, or four layers, and eleven straps to secure loads consisting of five or more layers. Also, a minimum of five straps is required to secure the load over the top layer on bundle or pack loads. Performance Pipe has developed packaging information to ensure pipe shipments are marked with warning labels placed on the pipe loads before shipment on flatbed trucks (Performance Pipe, 2013).

The Plastics Pipe Institute (PPI, 2021), American Pipeline Contractors Association (APCA, 2012), Uni-Bell PVC Pipe Association, and the manufacturers of PVC pipe offer guidance related to pipe loading, securement, transport, unloading, and truck driver safety. Commercial truck driver training aids, such as the cargo securement sliding calculator (J.J. Keller, 2023), can be used to determine proper payload securement based on the type of truck tie-down strap and the weight of the load. OSHA, MSHA, and ANSI forklift safety standards provide general safety practices and requirements for safe handling of pipe bundles during the loading and unloading processes.

ASTM D4675-14 Standard Guide for Selection and Use of Flat Strapping Materials (ASTM D4675, 2014) contains information on flat strapping materials to guide the user in selecting a strapping material and provides information on suggested application methods for use in packaging and loading applications (load unitization and securement to transport vehicle). This ASTM D4675 Guide provides safety hazard guidelines, general strap properties, and requirements for strapping joint strength. The PAC Strapping Products Plastic Strapping Guide (PAC Strapping Products, 2022) contains an equation for specifying strap

Figure 1. Pipe Bundles During Transport (A), Before Unloading (B), and After Incident (C)

product breaking strength, which is influenced by several factors such as weight, strap intended use, handling characteristics, and load characteristics. For palletized cases, the formula to determine the required tensile strength of the strap material is:

$$\text{Pallet Weight} \times 1.5 / \text{Number of Straps} = \text{Required Tensile Strength} \quad (1)$$

2. Case Studies

Two case studies of unstable PVC pipe bundles are presented in this paper to illustrate best safety practices associated with loading, transportation, and unloading of PVC pipes relative to flatbed trailers. The first case study involves failures of the green PET straps used to band the PVC pipe bundles and failures of the truck tie-down straps used to secure the pipe bundles to the flatbed trailer during transport, which contributed to the instability of the pipe bundles during unloading of the pipe bundles from the flatbed trailer. The second case study is associated with instability of the pipe bundles during transport due to the initial loading and stacking process of the pipe bundles, which resulted in the pipe bundles falling during unloading from the flatbed trailer.

2.1 Case Study 1 – Failed Polyester Straps

2.1.1 Introduction

This case study addresses a grouping of PVC pipe bundles that fell during unloading from a flatbed trailer, resulting in the death of the truck driver. Each pipe was approximately 1 foot in diameter, 20.5 feet long, with a dimension ratio (outer diameter / minimum thickness) of 18 and weighed 400 pounds. The pipe bundles consisted of stacked rows of three or four PVC pipes. The pipe bundles were made by a worker using a hand-held tool that applied and welded a green PET strap around the pipes and wooden dunnage. Each horizontal pipe bundle was secured with three green PET straps. There were no straps securing one pipe bundle row to another pipe bundle row. The two end green PET straps secured the wooden dunnage to the pipe bundles. Three pipe bundles and four pipe bundles were loaded on the flatbed trailer. Before transport, three truck tie-down straps were used over the top of a pipe stack and two truck tie-down straps were situated at mid height of the pipe stack.

During transport, one of the truck tie-down straps became partially torn due to the dynamic loading conditions. Photographic and video evidence indicates that that the PVC pipe payload was unstable during the transportation process. Broken and crooked green PET straps and significantly shifted dunnage underneath the foundational pipe bundle on the trailer increased the instability of the pipe bundles. Two of the three bottom green PET dunnage straps on the ends of the PVC pipe bundle failed during transport, leaving only the middle green PET strap intact. Figure 1A shows the four pipe bundles on the passenger side of the trailer during transport.

During unloading, the truck tie-down straps were removed from the pipe bundles. A loader with a fork attachment was used to unload the pipe bundles from the trailer three rows at a time. Figure 1B displays the loader operator's view of the PVC pipe bundles at the time of the unloading process. During the unloading incident, the single green PET strap in the center of the bottom pipe bundle would have been insufficient to maintain integrity of the forward passenger side bottom foundational pipe bundle, causing the entire stack of pipe bundles to become unstable during unloading. Figure 1C illustrates the fallen pipe bundles after the incident.

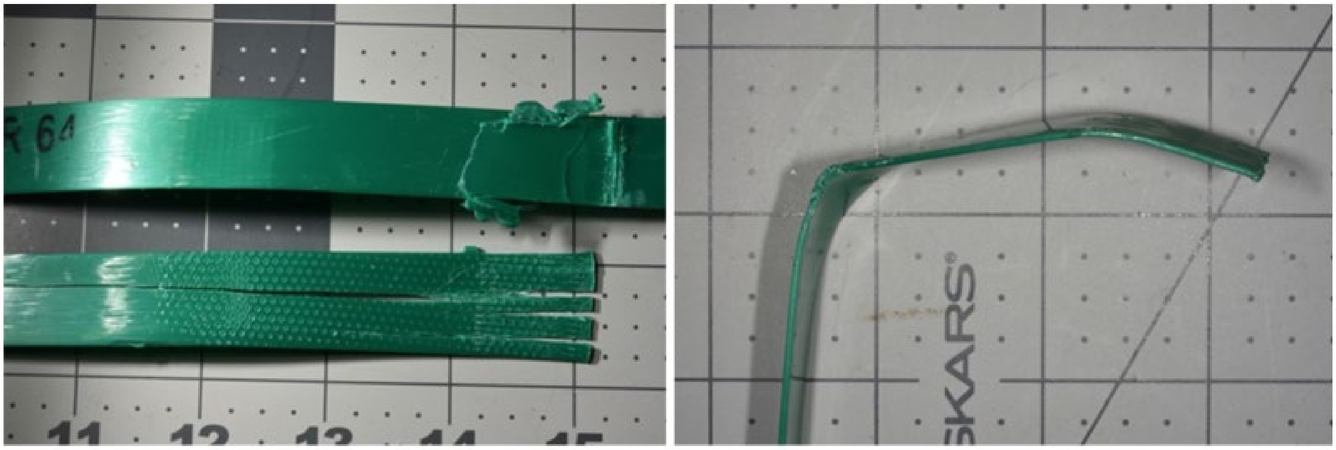

Figure 2. Green PET Strap Weld Failure (Left Image) and Green PET Strap Failure at Bend (Right Image)

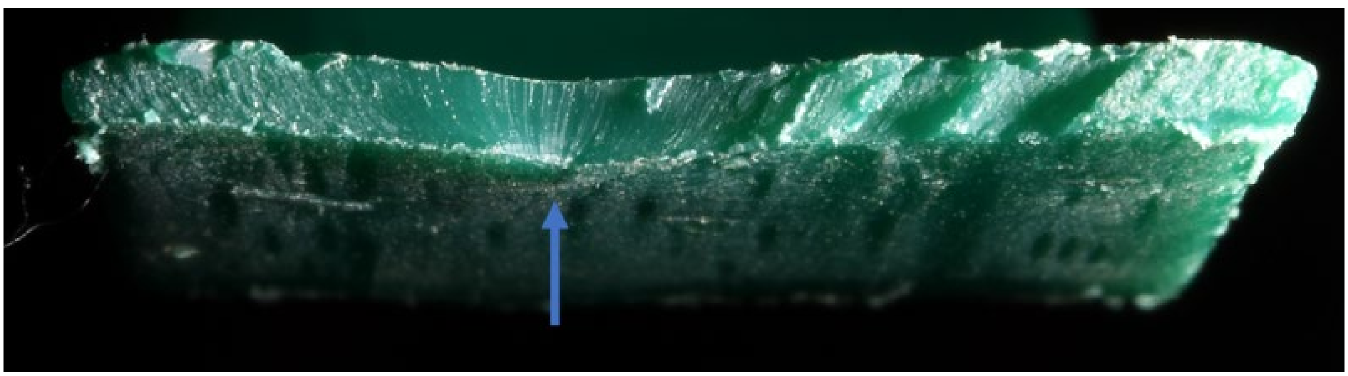

Figure 3. Green PET Strap Fracture Surface Indicating Tensile Overload Failure from Outside Surface

2.1.2 Analysis

Examination of the 0.75-inch-wide and 0.050-inch-thick green polyester (PET) straps from the incident scene was conducted. Studying the failed green PET straps from the incident scene revealed that they had failed either at a weld location or at a location of a stress concentration, such as at or near a sharp (90 degree) corner where the strap material was bent along the wooden dunnage. Figure 2 shows the two types of failure modes observed in the broken green PET straps used to bundle the PVC pipes.

As shown in Figure 2 (left image), the appearance of the green PET strap weld failure indicated that the weld was not properly made. There was evidence of misalignment of the two ends of the green PET straps as well as presence of molten material outside of the weld region. According to the green PET strap manufacturer, material outside of the weld region is an indication that the banding tool operator utilized excessive heating time or the operator utilized improper welding tool settings.

As displayed in Figure 2 (right image), the permanent residual bend and yielding at the failed green PET strap location indicates that the PET strap material experienced loads beyond the work capability (elastic property) of the PET strap. Figure 3 demonstrates the fracture surface of a green PET strap that failed near a corner. There is clear evidence of tensile fracture originating from the outside surface of the green PET strap. The green PET strap failed in a tensile overload mode experienced by the polyester strap material. The hackles and the ductile morphology are indicative that the green PET strap material was overloaded in the uniaxial direction. The hackles seen in Figure 3 on the fracture surface are emanating from an origin location.

Figure 4. PVC Pipe Payload Prior to Leaving for Destination (Left) and After Incident (Right)

Equation 1 was applied to the green PET strap application in this case study application. Three green PET straps were used to palletize a bundle of three or four large diameter PVC pipes. This required that the green PET strap tensile strength to be a minimum of 2666 pounds for a bundle of four pipes (each pipe weighs approximately 400 pounds) or a minimum of 2000 pounds to secure a bundle of 3 PVC pipes. The published value of the 0.75-inch-wide by 0.050-inch-thick green PET strap was 2500 pounds. However, the tensile strength value is lower when the green PET strap is tested in a configuration of a sharp bend, such as around wooden dunnage, as well at the weld locations. The weld strength of the green PET strap is reported to be up to 75 percent of the overall strength. Test results of the green PET strap indicate that the strap would fail at approximately 1500 pounds when tested against sharp corners due to a stress concentration effect. Given the lower strength of the PET green straps at the weld and at corners, an insufficient number of green PET straps were used in the bundling of the PVC pipe bundle load to accommodate both the static load as well as the dynamic loading imparted on the PET straps during transport. Since only three green PET straps were utilized to secure the PVC pipe bundle load during transport, the static and dynamic loads experienced by each PET strap exceeded the material strength, leading to PET strap failure either at the weld or at sharp corners.

2.2 Case Study 2 – PVC Pallet Payload Stability

2.2.1 Introduction

This case study addresses PVC pipe bundles that fell during unloading from a flatbed trailer. The fallen pipe bundles struck and injured the truck driver. The payload consisted of pipe bundles of various pipe diameters and types stacked on top of each other without any additional dunnage. The payload was to be delivered to two different customer locations. The pipe bundles were arranged on the flatbed to support the sequence of delivery to the two customers. Nylon ratchet straps were used to secure the payload to the trailer, with some of the straps securing a portion of a stack of pallets and others spanning the entire vertical stack of pallets (Figure 4A). At the time of the incident, the first delivery had already been made, resulting in a portion of the remaining payload having to be resecured to the trailer prior to transport to the second customer.

After arriving at the second customer's location, the truck driver loosened all the payload securement ratchet straps on the driver's side. Then the truck driver walked to the passenger's side to unhook the straps and throw the hook ends over to the driver's side or on top of the payload of pipe. At this point, the truck driver conversed with a forklift operator who then began to unload the pipe bundles from the passenger's side of the trailer. The truck driver returned to the driver's side of the trailer and began to roll the loosened straps back onto the ratchets attached to the trailer. At some point, the front stack of pipe pallets fell, striking and injuring the truck driver (Figure 4B).

2.2.2 Analysis

Images taken before transport and delivery of the payload (Figure 4A) exhibits an improperly loaded and unstable payload of PVC pipe pallets. Heavier pallets of PVC pipe were stacked on top of lighter pallets, resulting in an elevated center-

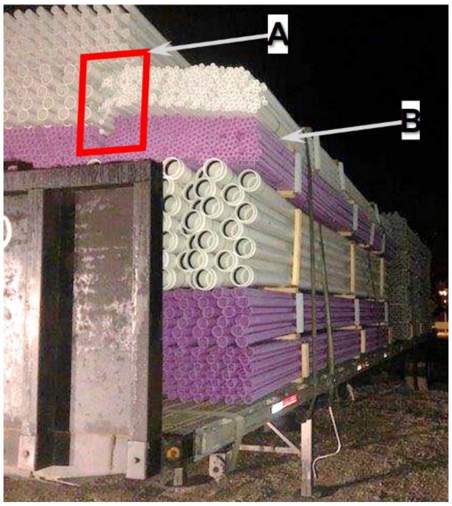

Figure 5. Payload of PVC Pipe Pallets Before Transport and Delivery – Stack of Pallets Misshapen (A) and Unstable (B)

of-gravity of the stack of pipe pallets. The pallets of pipe were also deformed and had caused the column of pallets to become misshapen, as shown in Figure 5 (A). The columns of PVC pipe pallets also became unstable, leaning outboard from the trailer as shown in Figure 5 (B).

These payload characteristics were not in compliance with Federal Motor Carrier Safety Regulations (FMCSR) or with requirements of the State in which the incident occurred. FMCSR 49 CFR 393.100 Subpart I regulates payload securement and stability, requiring that:

- The payload is to be secured to prevent it from falling from the vehicle.
- The payload must be secured to prevent shifting and destabilization of vehicle.
- The payload securement must withstand 0.8 g deceleration, 0.5 g lateral and 0.5 g acceleration.
- The payload cribbing, chocks, and blocking must be free from defects such that their effectiveness is not compromised.
- The payload must be "firmly" immobilized.
- The payload that is likely to roll must be secured with wedges.
- The payload must not be unintentionally unsecured and allowed to roll during transit.
- The payload must not shift toward one another while in transit.

In addition to the above FMCSR requirements, commercial motor vehicle requirements for the State concerned are to ensure that a payload is not loaded "top-heavy" and is balanced, keeping the center-of-gravity of the payload low.

The subject payload was improperly loaded and out of compliance with FMCSR and State regulations, resulting in an unstable stack of PVC pipe pallets. This instability existed before the payload was ever transported for delivery. Securement by the ratchet straps, as well as accelerations experienced by the payload during transit, further destabilized the payload. The payload should have never been transported in this condition, which created an unstable stack of PVC pipe pallets when unsecured for unloading. It could not be determined if the pallets fell from the trailer on their own after the ratchet straps were removed or if the pallets fell due to unloading by the forklift operator.

3. Conclusions

There are regulations and guidance available to safely load, secure, and transport PVC pipe bundles. FMCSA regulates payload securement and stability and the truck driver's related responsibilities. Pipe industry organizations offer guidance regarding pipe loading, securement, transport, unloading, and truck driver safety. Commercial truck driver training aids can be used to determine proper payload securement based on the type of truck tie-down and the weight of the load. OSHA, MSHA, and ANSI forklift safety standards provide general safety practices and requirements for the safe handling of pipe bundles during the loading and unloading processes.

The two case studies presented in this paper illustrate insufficient PVC pipe bundling and payload stability, resulting in accidental loss of the pipe load from the flatbed trailer. Current industry standards and guidance are varied and do not specify proper truck tie-down strap tension for all payload types, which is to be determined by the truck driver. Furthermore, the securement and stability of the payload is dependent on the strap material, strap tension, and the number of straps used for PVC pipe bundling. The method of PVC pipe bundle positioning and securement is not standardized in the PVC pipe industry. Stress concentration effects caused by the strap joining methods and dunnage used should be considered to determine the appropriateness of the strap material and the number of straps necessary for a particular load application.

4. References

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