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Trencher - Impingement on Buried Objects

By Dennis B. Brickman * and Ralph L. Barnett **

ABSTRACT

There is a resemblance between the digging chain of a trencher and the folklore chain saw. The safety of trenchers requires that the similarities and differences between these two machines be understood so that appropriate warning signs can be formulated. There is a notion that the trencher can be suddenly thrust rearward in the direction of the digging chain in the manner associated with the chain saw. There is also a notion that the kickback characteristic of the chain saw is also characteristic of a trencher digging chain. This paper shows that these rearward thrust and kickback notions for the trencher are false. On the other hand, contact with moving teeth is hazardous on either machine.

INTRODUCTION

This paper addresses chain trenchers of the type shown in Fig. 1a and Fig. 1b. Various components of the trencher are identified in Fig. 1a where the transverse directions are noted. The symmetrical nature of the excavating elements is depicted in Fig. 1b. A testing program was conducted using a 37.5 gross horsepower rubber wheeled chain trencher with a hydrostatic transmission. This trencher has a 1.22 m (4 ft) boom equipped with a rock and frost digging chain. The specifications of this trencher are shown in Table 1.

Chain contact can occur when a person's body is moved into the trajectory of the digging chain teeth. This occurs when flexible elements such as buried wires snare an operator and draw him into the direction of the moving digging chain. In addition, an operator can contact the moving digging chain by falling into the trench during a cave-in. In both of these scenarios, the trencher and digging boom positions are essentially stationary. There is a hypothesis which suggests that a stationary worker can be run down by the trencher when it is suddenly thrust in the rearward direction into the previously excavated trench. Under these conditions, if a worker is unable to retreat in a timely fashion, digging chain contact can occur. The same condition would result if the digging boom could kick back by rotating upward about the boom foot pin or about the axle which is furthest away from the digging chain.

Application of the safety hierarchy (1) to chain contact problems reveals the following strategies:

1st Priority: The function of the digging chain produces an intrinsic hazard which currently cannot be eliminated.

2nd Priority: Safeguarding devices are presently unknown for controlling the digging chain contact hazard while maintaining functionality.

3rd Priority: On-product warning signs appear to have potential for controlling the digging chain contact hazard.

4th Priority: Training and instruction including safety information contained in operator's manuals and the Equipment Manufacturers Institute's Trencher Safety

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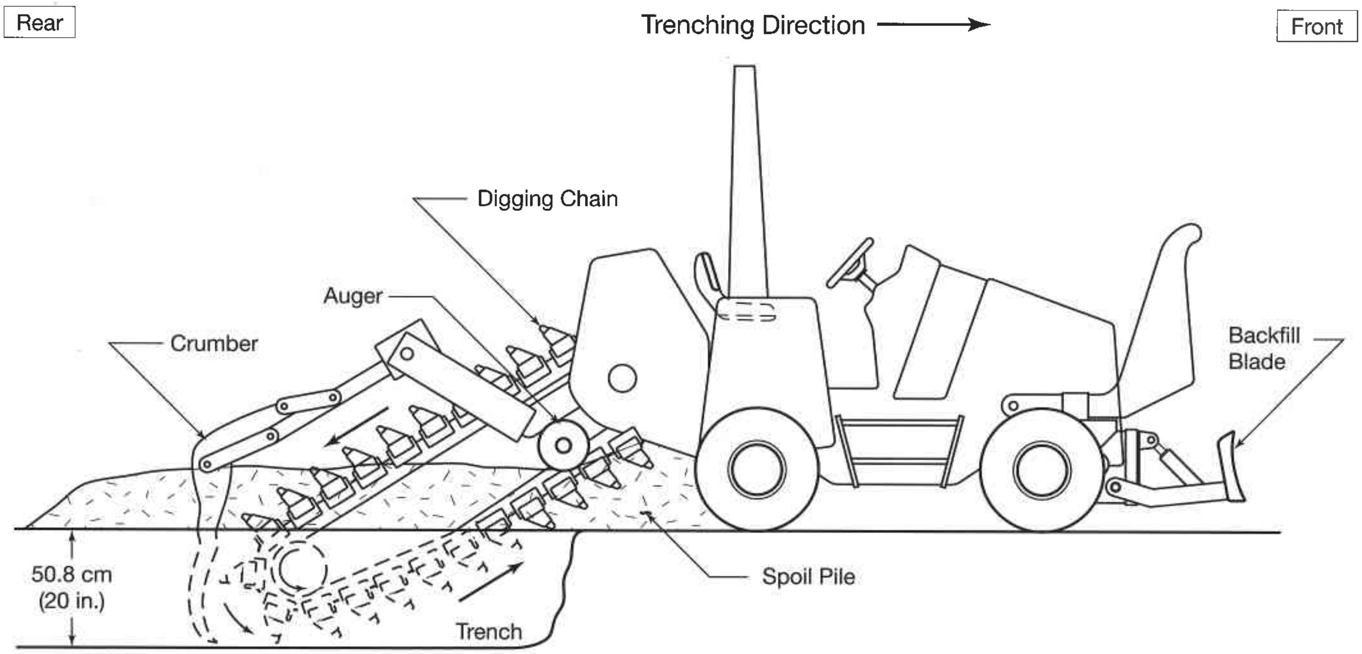


Fig. 1a: Trencher Side Elevation

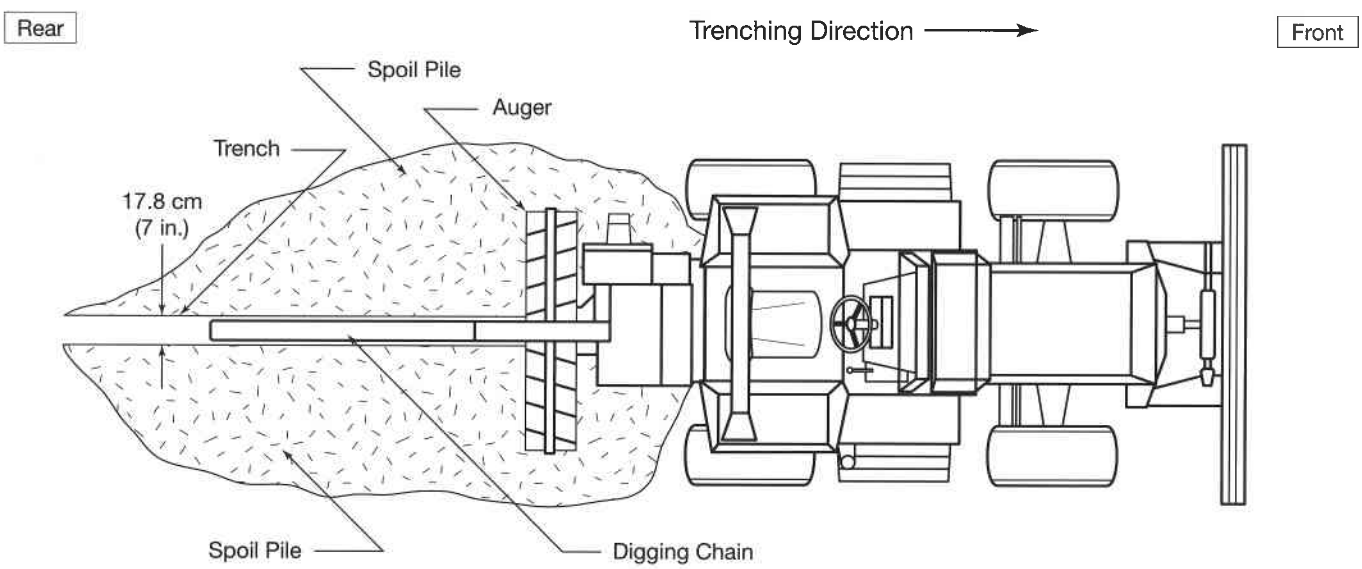


Fig. 1b: Trencher Plan View

Manual (2) also appear to have potential for eliminating or mitigating the dangers associated with digging chain contact. Like the warning signs, training affects the workers' personal vigilance and exploits this as a safety intervention technique.

5th Priority: The final step of the safety hierarchy is to exploit personal protection equipment. Unfortunately, the powerful and tenacious nature of the digging chain cannot be resisted by known protective clothing.

The safety hierarchy suggests that the use of warnings and training is currently the most effective accident prevention strategy. In this regard, it is important to accurately reflect the actual behavior of trenching machines and not their speculated or hypothesized behavior. It is clear that a call for strict avoidance of either advertent or inadvertent contact with the digging chain is unassailable. Indeed, current practice utilizes admonitions which address this behavior. On the other hand, sudden rearward movements of the digging chain caused by boom kickback or rearward translation have not been perceived by the trenching industry as failure modes. They have, however, been postulated by some members of the safety community. This paper explores these important hypotheses because of their impact on the formulation of proper warning signs.

To cause motion in the longitudinal direction, a net longitudinal force must be exerted on the trencher. There are three

Table 1: Trencher Specifications

Operating Weight:	**2,778 kg (6,124 lb)**
Travel Speed:	**6.2 km/hr (3.7 mph)**
Trenching Speed:	**0.168 km/hr (0.1 mph)**
Trench Depth:	**1.22 m (4 ft)**
Trench Width:	**15.2 cm (6 in.)**
Boom Angle Down from Horizontal:	**60° max.**
Angle of Departure:	**33°**

fundamental forces that must be considered: digging chain reactive forces, wheel chock forces, and tractive forces. The digging chain reactive forces arise from the contact of the digging chain teeth with the soil or buried objects. The maximum reactive force of the digging chain used in our testing program was limited by a pressure relief valve that capped the torque of the hydraulic chain drive motor. The direction of the forces will depend on the boom angle and there will be a longitudinal component of these forces that will tend to drive the trencher rearward. Opposition to the reactive forces arises from the tractive effort of the trencher in the forward direction. When the trencher is not driving forward, the frictional and interference drag at the interface between the operating surface and the wheels will tend to resist the reactive forces. The hydrostatic transmission of the test trencher cannot be back driven. Under normal circumstances, the tractive effort will always overcome the longitudinal reactive component. Otherwise, trenching could not be accomplished. It should be noted that the reactive forces of the digging chain also give rise to a vertical downward force on the trencher which increases the friction component of the tractive effort. As the trencher operates, two transverse augers create spoil piles in back of the rear wheels. These spoil piles act as wheel chocks behind the rear wheels and are available to resist rearward motion of the trencher. Consequently, any effort of the reactive digging chain forces to move the trencher rearward will be resisted by the spoil pile chocking resistance and the tractive effort of the trencher.

TESTING PROGRAM

A worst case scenario testing program was formulated to establish the validity of two hypothetical failure modes:

1. Rearward translation of the trencher can be achieved under digging conditions.
2. Kickback of the trencher boom can be achieved under digging conditions.

The following conditions were adopted throughout the testing program because they tend to exacerbate the hypothetical behavior:

1. A shallow digging boom angle (30 degrees) was used to provide a large rearward driving component with respect to the digging chain. It should be noted that a vertical digging boom transmits an almost vertical force component to the trencher.
2. Critical digging conditions are encountered when the digging chain contacts relatively rigid buried elements. To simulate such conditions, three buried elements were studied: 6" by 6" treated lumber, a 1.83 m (6 ft) long 10.2 cm (4 in.) diameter steel pipe, and a reinforced concrete parking barrier. The bottom edges of these elements were buried horizontally 50.8 cm (20 in.) below the surface in a direction perpendicular to the trenching trajectory.
3. All of the trenching operations were performed at the lowest digging chain speed which is recommended for hard trenching conditions.
4. The trenching tests were conducted with a rock and frost digging chain equipped with worn teeth loosely held in position. This combination produced an inefficient cutting action.
5. The operating conditions were such that the digging chain resistance produced a stall condition for the trencher. The full power of the machine was exploited repeatedly in trying to cut through the three buried obstacles.
6. The soil conditions for the basic trenching operation consisted of compacted soil containing rocks and asphalt. The chosen site was in a machinery traffic pattern that was regularly compacted with a roller.
7. The testing was conducted on 12/21/98 under 50°F conditions.

TEST RESULTS

On 12/21/98 between 10:00 a.m. and 5:00 p.m., a series of trenching tests were performed which included three buried interference devices. Repeated dynamic trenching and stationary trenching tests were conducted for all three obstructions with similar results. The tests were recorded on videotape.

<u>Treated Lumber</u>

<u>Dynamic Trenching</u>. A conventional 17.8 cm (7 in.) wide trench was excavated at a depth of 50.8 cm (20 in.). Eventually the digging chain impinged upon the treated lumber under creep conditions which extended 15.2 cm (6 in.) into the trajectory of the digging chain. The following behavior was noted:

1. Controlled vertical vibration of the trencher was observed where the maximum amplitude of the vertical displacements was observed at the lumber obstacle to be of the order of the 5.08 cm (2 in.) tooth depth.
2. No horizontal rearward translation of the trencher was observed.
3. No kickback or rigid body rotation occurred; that is, no rotation at the boom foot pin and no rotation at the front wheels.
4. The digging chain did not stall out.
5. The trencher engine did not stall out.
6. The trencher had not cut through the lumber when the test was terminated.

<u>Stationary Trenching</u>. With the trencher stationary, the boom was repeatedly raised and lowered until the moving digging chain cut through the buried lumber obstruction. The following behavior was observed during this part of the testing protocol:

1. Controlled vertical vibration was observed where the maximum amplitude of the vertical displacements at the lumber contact location was of the order of the tooth depth.
2. As the boom was brought into contact with the lumber, the digging chain stalled out nine times and the operator raised the boom to resume operating speed.
3. When the boom was lowered into the wood obstruction and the digging chain stalled, a rearward translation of the trencher caused the rear wheels to move toward the spoil piles; the wheels did not roll up the piles. The rearward translation was limited to 5.08 cm (2 in.).
4. No kickback or rigid body rotation occurred.
5. The trencher engine stalled out once.
6. The trencher eventually cut completely through the lumber.

Steel Pipe

Dynamic Trenching. A conventional 17.8 cm (7 in.) wide trench was excavated at a depth of 50.8 cm (20 in.). Eventually the digging chain impinged upon the 10.2 cm (4 in.) diameter steel pipe under creep conditions. The following behavior was noted:

1. Controlled vertical vibration of the trencher was observed where the maximum amplitude of the vertical displacements was observed at the pipe location to be of the order of the tooth depth.
2. No horizontal rearward translation of the trencher was observed.
3. No kickback or rigid body rotation occurred.
4. The digging chain did not stall out.
5. The trencher engine did not stall out.
6. The trencher had not cut through the pipe when the test was terminated.

Stationary Trenching. With the trencher stationary, the boom was repeatedly raised and lowered until the moving digging chain contacted the steel pipe obstruction. The following observations were made:

1. Controlled vertical vibration was observed with maximum amplitude of the vertical displacements at the pipe contact location of the order of the tooth depth.
2. As the boom was brought into contact with the pipe, the digging chain stalled out and the operator raised the boom to resume operating speed. This condition was achieved three times during the testing.
3. When the boom was lowered into the pipe obstruction and the digging chain stalled, a rearward translation of the trencher caused the rear wheels to move toward the spoil piles. The wheels did not roll up the piles. The rearward translation was limited to 5.08 cm (2 in.).
4. No kickback or rigid body rotation occurred when the digging chain contacted the pipe obstruction.
5. The trencher engine did not stall out.
6. The trencher had not cut through the pipe when the test was terminated.

A video sequence of the digging chain contacting the steel pipe is presented in Fig. 2.

Reinforced Concrete Parking Barrier

Dynamic Trenching. A conventional 17.8 cm (7 in.) wide trench was excavated at a depth of 50.8 cm (20 in.) until the digging chain impinged upon a reinforced concrete parking barrier under creep conditions. The following observations were noted:

1. Controlled vertical vibration of the trencher was observed where the maximum amplitude of the vertical displacements at the concrete parking barrier location was found to be approximately the tooth depth.
2. As the digging boom was brought into contact with the concrete parking barrier, the digging chain stalled out twice.
3. When the digging chain stalled as the boom was lowered into the concrete obstruction, a maximum rearward translation was limited to 5.08 cm (2 in.)
4. No kickback or rigid body rotation occurred.
5. The trencher engine stalled out once.
6. The trencher had not cut through the concrete parking barrier when the test was terminated.

Stationary Trenching. With the trencher stationary, the moving digging chain contacted the concrete obstruction until it was cut through. The following test observations were made:

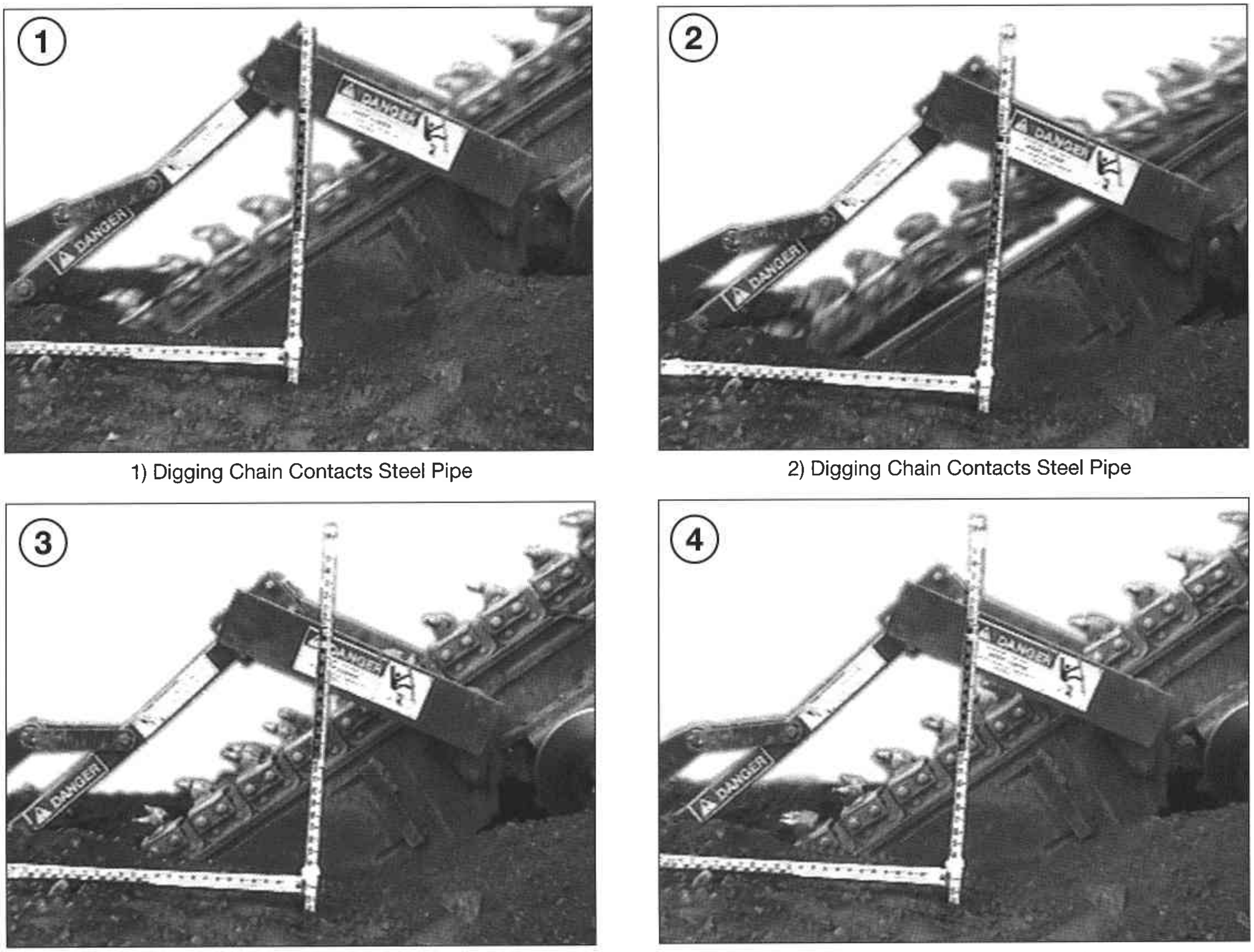
1. Controlled vertical vibration of the trencher with a maximum vertical displacement of 5.08 cm (2 in.) was observed at the concrete parking barrier.
2. As the boom was brought into contact with the concrete parking barrier, the engine stalled once.
3. When the boom contacted the concrete parking barrier and the engine stalled, a rearward translation of the trencher was limited to 5.08 cm (2 in.).
4. No kickback or rigid body rotation occurred.
5. The trencher cut through the concrete parking barrier.

ACCIDENT STATISTICS

This section presents the entire Occupational Safety and Health Administration (OSHA) file relative to trencher accident investigations which includes all case studies reported from 1980 through 1998 (3). With the exception of the deletion of the identity of the trencher manufacturers, these narratives are quoted as they appear in the OSHA accident investigations for trenchers. **The text has not been edited**. Perusal of these accident descriptions reveals no references to rearward translation or kickback. The OSHA trencher accident data are consistent with the findings of the testing program.

7/7/98 Summary #200710564

On July 7, 1998, at the 9500 block of Boat Club Rd, at approximately 2:30pm, an employee, an experienced operator, was operating a rock trencher to lay electrical conduit for a new residential housing sub division. The employee was operating the trencher and hit an "unmarked" line, resulting with the employee receiving extensive thermal burns involving approximately 98 of his body. The employer had called 1-800



1) Digging Chain Contacts Steel Pipe

2) Digging Chain Contacts Steel Pipe

3) Digging Chain Stalls Out

4) Digging Chain Stalls Out

Fig. 2: Video Sequence of Digging Chain Contacting Steel Pipe

Dig Tess to get authorization to dig; there were two lines running parallel and TU pipeline received the order, and lines supposedly were marked, per the RailRoad Commissions report. There are statements conflicting on whether or not both lines were marked.

8/13/97 Summary #201790243

Employee was removing dirt with shovel, while working behind a trencher, when shovel came in contact with chain drive causing the handle to kick-back and hit employee in left side of neck. Employee fell to ground, but continue working that day. Employee did not seek medical attention. Employee went home and felled a sleep and awoke the next morning for work, EE became disoriented and had trouble walking and could not speak. Medical services was called and EE transported to medical center. EE suffered a severed blow to the artery causing blood clot. EE was pronounced dead on August 17, 1997.

3/18/96 Summary #014228308

Deceased employee was attempting to load a trencher machine onto a trilers, when apparently he drove the trencher over the sie or it tipped over, while driving up the loading ramp. He fell out of the seant, and the trencher fell over on him, resulting in fatal injury.

11/15/95 Summary #171020332

On November 15, 1995, Employee #1, owner and sole employee of J.C. Enterprises, was moving a trencher and became caught in the equipment. He sustained multiple fractures and was killed.

5/17/95 Summary #170401103

Employee #1 was inside a 20 in. Deep, 7 in. wide trench when the trencher machine caught his pants and dragged his leg into the machine's moving chain drive. The employee was flown by helicopter to University Hospital Trauma Center in Newark, where his leg was amputated.

8/31/94 Summary #170617039

Employee #1, a field supervisor for Safety Electric Corp., was standing within 2 ft of a trencher, watching the operation, when the ground gave way. He fell into the digger chain and suffered a lacerated leg. He was hospitalized.

1/12/94 Summary #170705271

Employees #1 and a coworker were at an oil and gas well location performing a trenching operation. The coworker left the site for approximately 10 minutes to get material from a storage yard. When he returned, an employee from another company informed him that Employee #1 was caught in the chain portion of the trencher. They immediately shut down the machine and called for assistance. Employee #1 died from his injuries.

3/14/91 Summary #000710624

At approximately 12:50 p.m. on March 12, 1991, Employee #1 was operating a trencher with a hydra-borer attachment. He and a coworker were boring a hole at a 45 degree angle in order to install a drop for a telephone line. There was approximately 40 feet of bore steel shaft exposed when Employee #1 lifted up the rotating shaft to obtain the correct angle. His clothes became caught by the moving shaft and wrapped around it flipping the employee feet first onto the ground approximately 15 to 20 times and wrapping even more tightly around the bore steel shaft. The coworker ran to the trencher to disengage the power take-off unit. He then checked on Employee #1 and called for assistance. Employee #1 was transported to Southern Oregon Hospital, and later transferred to Rogue Valley Medical, Oincomplete record-ERGa.

10/24/90 Summary #000903328

At approximately 8:47 a.m. on October 24, 1990, a two-ton diesel truck, traveling south at a high rate of speed in the passing lane of a three lane highway, rear-ended a utility truck pulling a trailer loaded with a trencher. The utility truck, now out of control, moved into the median and was struck again in the rear by the truck. The truck then came around and struck the utility truck a third time in the side. The truck continued south in the passing lane, then crossed the median about 1 mile from the initial accident and struck Employees #1 and #2, construction workers, as they worked in the 36-foot wide median. From there, the truck traveled across the northbound lanes through traffic and down an embankment on the right-of-way. The truck went through a fence and into a parking lot, where it struck a parked vehicle, knocking it into an office building before it also hit the building and came to a stop. Employee #1 sustained serious head and internal injuries and died at the hospital. Employee #2 received lacerations and bruises on his leg and arm and was treated and released from the hospital.

8/18/89 Summary #000884593

Employee #1 was operating a trencher. He dismounted the machine and left it running. While the employee watched the trencher in motion, the ground gave way and he fell into the trench. Employee #1 became caught by the trencher and was killed.

6/8/89 Summary #000801324

Employee #1 and two other employees had set up a trencher with a 6 foot chain in preparation to lay cable tv lines. Since it was close to lunch time employee #1 sent the other employees to lunch. The employee #1 was digging a trench about 2 feet deep when the trencher stopped digging-becoming stuck. The employee got off the seat with the trencher still running to dislodge the chain, the chain started running again catching the employee and pulling him into the chain amputating his leg and severlywoulding his arm (amputated) and is in danger of losing his whole arm.

6/14/88 Summary #014453781

Employee #1 was removing a plastic sheet from a #144 offset rubber tire trencher after painting. His right fingertip was amputated by the chain and sprocket on the trencher.

6/16/86 Summary #014565907

Employee #1 was trenching to install underground wiring for installing street lighting on a street improvement project employee #1 running the trencher then hit a 2" plastic gas line & ruptured it causing a fire resulting in burns to employee #1 about the face, arms and hands employee #1 was hospitalized at st. marys hospital

7/31/84 Summary #014550081

Employee #1, a lead mechanic, was performing routine maintenance work on a trencher. He was sitting “indian style” on the floor immediately behind the right front wheel. He could not reach the oil plug so he asked an operator to start the trencher and turn the wheels so he would have easier access to the plug. When the engine started it rolled backward over employee # 1. Evidently, he had moved the “creep” gear liver into reverse, either on purpose or by accident

There are several failure modes identified in the OSHA accident investigation narratives. Specifically, 50% of the trencher accidents reported by OSHA arise from advertent or inadvertent body contact with the digging chain. On the other hand, it should be emphasized that no kickback or rearward translation accidents were reported.

CONCLUSIONS

Results from the testing program indicate the following:

1. No rigid body rearward translation was observed under normal digging conditions in compacted hard soil containing numerous fist size rocks and asphalt. Contact with three buried obstructions in the form of 6” by 6” treated lumber, 10.2 cm (4 in.) diameter steel pipe, and a reinforced concrete parking barrier did not produce rigid body transverse motions.
2. Excavating in the creep mode in compacted hard rocky soil did not produce visible transverse vibrations of the trencher. On the other hand, contact of the digging chain with the buried obstructions during stationary operations produced visible vibrations whose fore and aft amplitude was limited to 5.08 cm (2 in.).
3. Conventional excavation under creep conditions in compacted hard rocky soil showed no indication of kickback where kickback is defined as an upward rotation of the digging chain about the boom foot pin or the front axle of the trencher. Furthermore, contact with the three buried obstructions at creep speed produced no rigid body rotation or kickback. Under

stationary conditions, lowering the digging chain into the obstructions did not reverse the boom movement. Rotation of the entire trencher around the front axle by the lowering action of the boom was observed on only one occasion; this was a slow jacking phenomenon and not a kickback.

4. During stationary operation, contact with the buried obstructions set up a visible vertical vibration whose amplitude at the station above the buried obstruction was limited to 5.08 cm (2 in.).

5. The hypotheses suggesting that kickback and rearward translation can occur were disproved by the results of the worst case scenario testing program. The test demonstrations indicate that intuition is a good servant but a bad master.

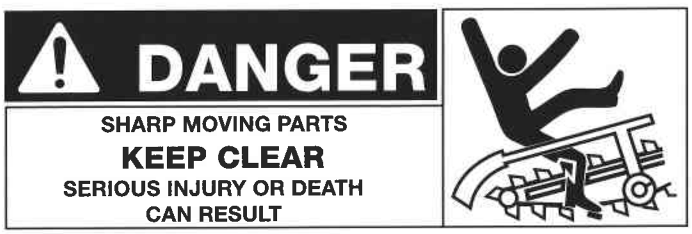


Fig. 3: Trencher On-Product Warning Sign

On-product warning signs, in-manual warnings and instructions, and verbal and written instructions should not address the issues of kickback and rearward translation. These phenomena do not exist and misinforming the public would not appear to have a net safety benefit. Whereas exaggeration of dangers may make warning signs more compelling, misstatements are eventually disproved by operators and all warnings are compromised as a consequence. Furthermore, the effectiveness of warning signs is diminished when large numbers of admonitions are exhibited. This phenomenon is called clutter (4). A current on-product warning sign dealing with digging chain contact is shown in Fig. 3. This warning is designed in accordance with the American National Standard for Product Safety Signs and Labels, ANSI Z535.4-1991(5). Elements of this warning include using the signal word "danger" (highest level), identifying the contact hazard (pictograph), describing countermeasures for controlling the danger, and finally giving the consequences of disobeying the warning sign. This warning identifies the danger associated with advertent and inadvertent chain contact. This warning does not describe kickback and rigid body translation. This is consistent with the OSHA trencher accident statistics and our research findings. It should be pointed out that on-product and in-manual warnings for construction equipment including trenchers have a special status. Employers are required by OSHA to train and instruct their employees to obey on-product and in-manual warnings under the Safety Training and Education section, 29 CFR 1926.21(b) (6).

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HALES NAMED CHAIR OF ASME DESIGN DIVISION

Triodyne engineer, Dr. Crispin Hales, has been named Chair of the Design Engineering Division of the American Society of Mechanical Engineers for 1999 - 2000. DED is the largest Technical Division in ASME, with ten Technical Committees covering all aspects of Design Engineering. It publishes three technical journals: *Mechanical Design, Vibration and Acoustics* and *Mechatronics*. DED will also run three large design forums this year: an interchange between researchers and practicing engineers at the National Manufacturing Week conference in March; joint Technical Conferences of Design Engineering and Computers and Information Engineering in September and; symposia at the ASME International Mechanical Engineering Conference and Exposition in November.

Dr. Hales is a Principal Mechanical Engineer at Triodyne specializing in the management and analysis of engineering design issues, mechanical safety and accident reconstruction. He joined Triodyne ten years ago with twenty years of experience in engineering design, principally in industry but also including research and teaching at undergraduate and post-graduate levels. In assocation with Cambridge University, he has helped to develop more effective design teaching and professional programs for young engineers.

Dr. Hales was the manager of a design group at IIT Research Institute which custom built a wide variety of research equipment. More than ten high-pressure testing systems for the evaluation of materials under extreme conditions were developed including a $3 million refractory test facility for the Department of Energy and a multi-specimen creep test facility for NASA.

Dr. Hales holds a Bachelors Degree in Mechanical Engineering from Canterbury University in New Zealand, a Masters Degree in Engineering Design from Loughborough University in England and a Ph.D. in Engineering Design from Cambridge University in England. He is registered professionally as a Chartered Engineer in the U.K. In addition to his involvment in ASME, he is a fellow of the Institution of Mechanical Engineers in Britain. He has written many papers, technical reports and book chapters in the field of engineering design and has also written a textbook called, "Mechanical Engineering Design" for Longman Scientific and Technical, Longman Group UK Ltd.

Crispin's focus for his tenure as ASME Design Engineering Division Chair will be on:

- Increasing international understanding, cooperation and participation in the field of design engineering.
- Strengthening links between industry and academia.
- Encouraging young people to enter the profession and to develop their potential within it.

Congratulations on this honor, Crispin, and good luck.

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