

# **Compactor Overturns and Rollover Protective Structures**



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Cover photo courtesy North Carolina Department of Labor.

## **Abbreviations**

CIMA	Construction Industry Manufacturers Association
FACE	Fatality Assessment and Control Evaluation
NIOSH	National Institute for Occupational Safety and Health
OMB	Office of Management and Budget
OSHA	U.S. Occupational Safety and Health Administration
ROPS	Rollover Protective Structure
SAE	Society of Automotive Engineers

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## Summary

Compactors – also known as steamrollers – are mobile vehicles used to increase the density of soil and roadways and to seal and smooth asphalt surfaces. Compactors tend to overturn during some operations, thus putting their operators at risk. A rollover protective structure (ROPS) is a part of a compactor or other heavy equipment designed to protect an operator from a crushing injury in the event of a rollover. Particularly with seatbelt use, ROPSs have been shown to save lives.

In 1971, the Employment Standards Administration, part of the U.S. Department of Labor, drafted the following language under the Construction Safety Act: “The promulgation of specific standards for rollover protective structures for compactors...is reserved pending consideration of standards currently being developed.” The newly established U.S. Occupational Safety and Health Administration (OSHA) adopted the language in its rules the following year. Although consensus standards were developed soon thereafter (by the Society of Automotive Engineers), the OSHA rules were never changed to require ROPS on compactors.

This study examined government investigation reports of work-related deaths and injuries in 1986-2002 to learn the public health implications of a widespread lack of ROPS and seatbelts on compactors. Among the findings:

- Operators and drivers have been killed or seriously injured as a result of a lack of ROPSs and seatbelts on compactors. Compactors with ROPSs were found to restrict overturns to 90°, whereas compactors without ROPSs were found to average more than two revolutions per event.
- Of 58 compactor overturns examined, nearly half involved the smooth-drum type of compactor, as compared with the steel-drum type and the pad-foot type.
- The highest overturn hazard locations were along roadway or embankment edges. The next-most-hazardous situation was runaway machines, typically down slopes.
- Compacting of soil appears to have been more hazardous than other compacting operations, especially for the smooth-drum and pad-foot compactors. Soil edges were a hazard, as were soft soil pockets that can drop under the weight of a unit.
- The stability of a compactor was affected by maintaining vibration while stationary, turning away from a slope with articulated steering, or using water as ballast, because water can slosh from side to side in the water tanks.
- Loading or unloading compactors on trailers posed potential overturn hazards; the hazards were caused by skidding on inclines by smooth-drum compactors, using wood blocks or planks as a ramp, or loading a narrow unit that lacks the width to reach both loading ramps.
- Failure to use a seatbelt when a compactor had an ROPS was a hazard. Some seatbelts were inoperable and some had not been installed on new compactors. However, using a seatbelt when there was no ROPS resulted in a death also.
- When an ROPS was reported as the part of a compactor that pinned or crushed an operator, in five instances where the reports were detailed, it was an overhead canopy that struck the operator.
- An OSHA directive in 1998 established that the lack of an ROPS and seatbelt on compactors is a hazard enforceable under the OSHA General Duty Clause.



Compactors, or steamrollers, are used to increase the density of embankments and roadways and to level and seal asphalt pavement. They have been indispensable in the construction of roads, streets, air strips, earthworks, parking lots, dams, levees, and railroad beds. Compaction is applied using pressure, kneading, impact, and vibration (Church 1981; Galion 1959). A rollover protective structure (ROPS) is a part of a compactor or other heavy equipment designed to protect an operator from a crushing injury in the event of a rollover.

Although ROPSs likely would save lives and prevent serious injuries of compactor operators, particularly with seatbelt use, the U.S. Occupational Safety and Health Administration (OSHA) has not promulgated a standard that would require the devices – and seatbelts – on compactors. The expectation for such a standard was based on a 1972 construction-equipment ROPS standard, which excluded compactors yet stated:

The promulgation of specific standards for rollover protective structures for compactors...is reserved pending consideration of standards currently being developed (29CFR1926.1000, p.327 ).

The following report uses government reports of work-related injuries and deaths to describe the hazards of construction work using compactors without ROPSs and with/without the added factor of seatbelt use.

Several questions drove the analysis. First, was a suggestion by Brickman and Barnett (1999) that ROPS present more of a hazard in an overturn than if they are not installed. Another is the question of the general effectiveness of ROPSs for compactors. A third issue has been the added value of seatbelt use. Fourth, what have been OSHA and industry responses thus far to the problem.

## **Background**

Decades ago, studies identified unstable embankment foundations as unable to support the weight of a compactor (Ritter and Paquette 1960, p. 374) and operating compactors at the edge of high fills as dangerous (Baker 1957). The Naval Training Command wrote that a “roller is easier to overturn than most other equipment,” adding that rolling a shoulder presents a risk of an overturn into a ditch (1973, p. 375).

Some early statistics indicated a pernicious problem related to compactor overturns. California reported 14 compactor overturn-related deaths between 1965 and 1972 (White 1973). Woodward Associates’ 1974 analysis reported 13 compactor overturn-related injuries during 1971 and 1972 in California.

The Construction Industry Manufacturers Association, CIMA, alerted the public to the hazard of operating compactors on slopes in a booklet (1978): “the danger of sliding and/or tipping on steep slopes is always present regardless of how heavy or stable your machine may appear to be.” The booklet identified the potential of caving edges also. CIMA recommended always wearing a seatbelt on a compactor that was equipped with an ROPS; avoiding operating a machine too close to an overhang, deep ditch, or hole; and always traveling slowly over rough terrain and hillsides.

Between 1950 and 1970, two ROPS standards emerged that affected construction equipment: a Society of Automotive Engineers recommended practice and U.S. Army Corps of Engineers design criteria. Besides the Army Corps move, several government entities established ROPS standards: the states of California and Oregon, and the U.S. Departments of Agriculture (Forest Service) and

Interior. In addition, several state highway departments specified ROPSs in purchase orders for construction and highway maintenance equipment.

### **The Society of Automotive Engineers Recommended Practice**

In 1966, the Society of Automotive Engineers (SAE) began developing recommended practices for protective devices for mobile construction and earthmoving equipment. The SAE developed a standard to allow an ROPS to yield through deformation and absorb some of the energy of a rollover so as to lessen the violence of the overturn. The structure was designed to deform through a plastic range that would neither break nor intrude into the operator's protective zone (National Safety Council 1976). It was not until 1975, however, that the SAE issued a recommended practice for ROPSs on compactors, classifying them as earthmoving construction equipment. In 1981, the SAE reclassified compactors as other than earthmoving machines (SAE 1975, 1981), thus removing compactors from a classification that included bulldozers, scrapers, and graders.

### **Army Corps of Engineers Requirements**

The Corps of Engineers began requiring heavy canopies as rollover protection on crawler tractors in 1960. In 1967, the Corps issued its Safety-General Requirements, which required steel canopies and seatbelts on any construction equipment that presented a construction hazard, including compactors (Article 18.A.20). The manual required a canopy design that would support twice the weight of the machine and provide at least a 52-inch clearance from the machine's deck to the roof of the canopy.

In 1970, the Corps issued a nationwide circular that required ROPSs to be used on construction projects; plus, whenever ROPSs were required for any part of a project, they were to be required for the entire project (Murphy 1970). The North Pacific Division of the Corps then issued a circular to establish a uniform policy for accepting ROPSs installed on construction equipment, which included rollers and compactors. Furthermore, because of the rough terrain on nearly all construction work and the potential number of rollovers in the Northwest, the Division required ROPSs unless specifically waived by the District Engineer (Zink 1970). In 1972, the Corps specified ROPSs on rollers and compactors (Woodward Associates 1974).

### **Other Governmental Actions**

Pursuant to the Construction Safety Act of 1969, the U.S. Department of Labor announced a notice of proposed rulemaking in 1971 to add Safety and Health Regulations for Construction to the *Code of Federal Regulations* (*Federal Register*, Feb. 2, 36:22). The proposed regulations included compactors as earthmoving equipment and required ROPSs to conform to SAE minimum-performance criteria. The final rule, published in 1971, read, "The promulgation of specific rules for compactors and rubber-tired "skid steer" equipment is reserved pending standards currently being developed." (*Federal Register*, April 17, 36:75)

With the passage of the Occupational Safety and Health Act (OSHAct), which took effect on April 29, 1971, publication of the construction rules in the *Code of Federal Regulations* was delayed until 1972, when OSHA published a rule for ROPSs that exempted compactors, as well (*Federal Register*, 37:66, April 5).



In 1972, however, OSHA notified the public that if a standard was reserved with a delayed effective date, the working conditions would be subject to the General Duty Clause, Section 5(a)(1) of the Occupational Safety and Health Act. Under this clause, OSHA may cite an employer for failing to provide a place of employment free from recognized hazards that are likely to cause death or serious physical harm. OSHA named the lack of an ROPS as such a hazard in certain situations, but also named other factors, such as machine speed, nature of the soil, the grade of the terrain, falling-object risk, and training.

In 1976, California issued safety regulations that required ROPSs and seatbelts on rollers and compactors (Division of Industrial Safety 1976).

The Office of Management and Budget issued its Regulatory Program of the U.S. Government for April 1, 1985 to March 31, 1986. In the document, OSHA stated its intention to amend the current ROPS standard so as to eliminate gaps in coverage and specifically named the problem of deaths associated with compactors. OSHA stated that the installation of ROPSs and seatbelts on compactors could have prevented deaths, but said seatbelts were not required in 1971 because of the unavailability of technology (OMB 1985) (see below).

In the meantime, Miles (1986), of the OSHA Directorate of Field Operations, specified that the General Duty Clause could be cited when compactors were used in a manner that posed a recognized hazard to the operator.

In preparation for the ROPS rule, OSHA established a task force to develop requirements for compactors (Richter 1987). The task force recommended that compactors be equipped with ROPSs, as specified in SAE Recommended Practice J1040 (1986); that ROPS be designed to support at least two times the weight applied at the point of impact; and seat belts meet SAE J386. The industry expected OSHA to require ROPSs on all compactors in late 1988, and at least one company planned to offer ROPSs on all of its compaction equipment as standard equipment (Richter 1987). OSHA never promulgated the rule.

In 1998, OSHA issued a guideline that recognized equipment rollover as a hazard under the General Duty clause. OSHA recognized that ROPSs and seatbelts were feasible to reduce this hazard (Swanson 1998).

## **ROPS Effectiveness and Availability**

Protective canopies for crawler tractors and anti-roll bars for agricultural tractors had emerged in the 1950s (Myers 2000). The first patent for an agricultural tractor protective frame was issued in 1954, and the first use of an anti-roll bar on roadside mowing tractors was in 1958 (Skromme 1986). Construction equipment canopies were available from several manufacturers in 1958 (MacCollum 1958). Protective structures were demonstrated to be effective as early as 1956 by the U.S. Forest Service in overturn tests conducted on crawler tractors (E&R 1956). Anti-roll bars on mowing tractors were designed to prevent a roll beyond 90°, which proved to significantly reduce deaths from this type of work. These tractors experience slope exposures similar to the edge work of compactors.

Starting in June 1973, Woodward Associates (1974) conducted a study for OSHA on the feasibility of retrofitting ROPSs on construction equipment, excluding compactors. Nonetheless, fatality data analyzed from California and the Corps of Engineers included compactors. The study concluded that ROPSs clearly reduced injuries and deaths related to vehicle rollovers. Moreover, the study found that ROPS designs were available for most heavy-construction equipment manufactured after 1960 and that rollovers occurred in all types of terrain and to all types of vehicles.

In Sweden, the use of ROPSs on agricultural tractors has proven to be effective in reducing death rates from 17 per 100,000 tractors in 1960 to 0.3 per 100,000 tractors, with a 98% compliance in 1990; using seatbelts can save additional lives (Myers 2000). In addition, ROPS have proven to be life-savers where they have been required on mining (Woodward 1980) and construction equipment (MacCollum 1984).

In 1976, Saf-T-Cab , an ROPS manufacturer, listed available rollover protective structures for virtually all compactors manufactured in the United States based on the Corps of Engineers design criteria (Woodward Associates 1976) ( table 1).

**Table 1. Rollover protective structures available from Saf-T-Cab, Inc., for compactors, 1976**

<b>Make</b>	<b>Model</b>
Bros	SP, SPV 370, SPV 725, SPV 735, SPV 845, SP 2800, SP 3000, SP 3500, SP 6000, SP 10000
Caterpillar*	814, 815, 824, 825, 830, 834, 835
Clark-Michigan	RW-140, RW-181
Galion	3-5, 5-8, 8-12, and 10-14 Ton Tandem; 10-12 and 12-14 Ton 3-Wheel; and 9-T-15 9-Wheel
Hyster	C-350A, C-451A, C-450, C-500, C-530, C-550
Ingersoll Rand	SP 42, SP 54
Ingram	3-5, 5-8, 8-12, 10-14 Ton; 8, 10, and 14 Ton 3-wheel; 9-2800P, 9-3400-P, 11-2700, and 13-2300
Koehring	60, 100, 140, K-550
Raygo/Wagner	2-36, 45, 80, 400, 404, 600; (Wagner) SF-17, WC-317
Tampo	RS-16, RS-28, RS-38, RS-166A, RH-48, RP-16, SP-312, SP-750, SP-950
Vibro Plus (Dynapac)	CA-25

\* includes wheel dozers

Source: Woodward Associates 1976.

## **Types of Compactors**

In 1973, the Society of Automotive Engineers described three types of compactors: tamping (pad) foot compactors, smooth steel rollers, and rubber-tired rollers in a nomenclature standard. The standard referred to compactors (also called “rollers”) as smooth-drum, pad-foot (sometimes called “sheepsfoot”), and rubber-tired (also called “pneumatic”) (figs. 1-3). Both the smooth-drum and pad-foot compactors were manufactured as double drum or single drum, and some had a vibration mechanism designed into the drum wheels to assist in compaction. Units lacking the vibration feature were called static compactors.

An alternative steering mode for many compactors is articulated steering. This combines a prime mover (with the engine) and a trailer that are tightly connected. Steering is through two hydraulic cylinders that push and pull at the connection.

On compactors, an ROPS can be designed with two posts or four posts (fig. 4) and can have a canopy overhead to provide shade; these canopies may be designed as part of the ROPS system. Some modern compactors use a single-post ROPS with a canopy extending to the sides to absorb the impact of an overturn. A principle in ROPS design is to restrict an overturn to no more than 90°.

## Research Methods

The collection of cases to be analyzed followed a two-step process. First, the researcher identified OSHA inspection reports and Fatality Assessment and Control Evaluation (FACE) investigations of compactor overturns and runovers by the National Institute for Occupational Safety and Health (NIOSH). Four of OSHA reports were also included in the NIOSH investigations. Most of the cases were found on the internet at the OSHA and NIOSH websites. Others were identified from newspaper articles, litigation files, and through assistance from the Portland, Oregon, Area OSHA Office. A total of 123 cases was identified.

The next step was to request the complete investigation report from OSHA under the Freedom-of-Information Act (although, to protect privacy, all names were expunged from the reports, except for decedents and officials representing the employers). The NIOSH reports were accessible through the internet.

Case files were compiled for 58 injury events involving compactor overturns (table 2). The cases ranged from the year 1985 to 2002.

Some OSHA reports related to the same incident; some addressed falls and collisions, as well as overturns. Eight others dealt with scheduled inspections in which the OSHA General Duty Clause was used to cite the lack of an ROPS or of a functioning seatbelt. OSHA data were not comprehensive and omitted many nonfatal events and all pre-1985 overturns, as well as incidents involving public employees where OSHA lacked jurisdiction.

Data from the reports were placed into a Haddon matrix to analyze the role of machine, environmental, and human factors and the temporal dimension (before, during, and after) of each incident (Runyan 1998; Hadden 1970, 1980). In addition, flowcharts were used to understand the factors that comprised the causal chain leading to and the characteristics of each overturn (Feyer and Williamson 1998; Myers 1992).

The Haddon matrix provided a way to categorize risk factors against three stages of an incident (*see* table 3). The first stage is pre-event (for example, compacting along an embankment edge); the second stage is the event (such as, an overturn); and the third stage is post-event (for instance, extrication). The risk factors were classified as related to the energy agent (such as, the compactor); the environment (for instance, a steep slope); and operator/driver (for instance, wearing a seatbelt).

Nonetheless, because of limitations in the data, this analysis can't show whether one type of compactor is more dangerous than the others; there is no way to know how much of the work was done using each type.

**Table 2. 58 compactor overturn cases analyzed, with associated characteristics**

State	OSHA Inspection Number	Yr	Injury Type	Type of Roller	ROPS Present	Seatbelt Present	Incident Type	Roll Over deg.	Operation	Comments
1 AL	300956950	96	fatal	rubber	No	No	edge	180	loading	anti-sloshing baffles in water tank
2 AR	107703555 107703563	92	fatal	pad	No	No	edge	180	soil	leg disability; unable to jump
3 CO	302071550	98	fatal	smooth	No	No	runaway	540	transport	ROPS removed
4 GA	101281608	87	fatal	pad	No	No	edge	190	soil	
5 GA	102834579	88	fatal	rubber	No	No	runaway	180	gravel	
6 IL	100089754	85	fatal	smooth	No	No	edge	900	asphalt	
7 IN	124019019	93	fatal	smooth	No	No	runaway	180	transport	
8 KY	115948929	91	fatal	rubber	No	No	runaway	unk	transport	
9 MD	302796149	99	fatal	smooth	No	Yes <sup>y</sup>	edge	180	soil	wore seatbelt
10 MN	104557012	87	fatal	pad	No	No	edge	1080	soil	
11 MN	111609665	90	fatal	rubber	No	No	edge	270	gravel	1963 model
12 MN	120400437 <sup>a</sup>	95	fatal	rubber	No	No	runaway	180	asphalt	
13 MS	017443771	88	fatal	pad	No	No	edge	90	shoulder	
14 MS	109070300	94	fatal	pad	No	No	edge	180	soil	articulated position
15 MS	109257709	95	fatal	rubber	No	No	edge	180	gravel	
16 NC	002998193	87	fatal	rubber	No	No	edge	unk	shoulder	dozer operator
17 NC	014992093	86	fatal	rubber	No	No	runaway	270	transport	turn angle problem
18 NC	302936265 <sup>b</sup>	00	fatal	smooth	No	No	edge	90	asphalt	asphalt sank, 1T unit
19 NM	300675071	99	fatal	rubber	No	Yes <sup>y</sup>	edge	180	soil	wore seatbelt
20 NY	115927170	92	fatal	smooth	No	No	edge	unk	shoulder	
21 OH	103040200	91	fatal	smooth	No	No	edge	90	asphalt	
22 OH	103336467	95	fatal	smooth	No	No	edge	180	shoulder	
23 OH	301530283	97	fatal	smooth	No	No	edge	180	transport	
24 OH	302510367	99	fatal	smooth	No	No	edge	220	asphalt	
25 OR	107298770	90	fatal	smooth	No	No	edge	360	chip-seal	
26 OR	115714776	91	fatal	smooth	No	No	edge	180	shoulder	vibrator on, stopped
27 SC	126476977	95	nonfatal	smooth	No	No	edge		soil	
28 SD	113327894	98	nonfatal	rubber	No	No	edge	180	shoulder	articulated position
29 TX	102338530	88	fatal	rubber	No	No	edge	630	shoulder	
30 TX	103609319	86	fatal	rubber	No	No	edge	450	shoulder	water ballast
31 TX	108761438	91	fatal	smooth	No	No	runaway	720	chip-seal	no brake fluid
32 WA	115328064	97	fatal	smooth	No	No	edge	180	shoulder	
33 OK	103637120	86	fatal	rubber	unk	unk	unk	unk	unk	riding double
34 SC	124654401	93	nonfatal	smooth	unk	unk	edge	180	loading	used only one ramp
35 TX	107562456	92	fatal	pad	unk	unk	edge	unk	transport	ramp
36 TX	101496586	89	fatal	unk	unk	unk	runaway	unk	in tow	
37 AK	124096314 <sup>c</sup>	97	fatal	smooth	Yes	Yes <sup>n</sup>	edge	90	loading	"top member of ROPS"
38 AR	110353844	93	fatal	pad	Yes	Yes <sup>n</sup>	edge	90	soil	struck "right top portion of the ROPS"
39 GA	302563101	00	fatal	pad	Yes	Yes <sup>n</sup>	edge	90	soil	ROPS struck victim; unbuckled belt to jump
40 GA	303378830	00	nonfatal	pad	Yes	Yes <sup>n</sup>	edge	90	soil	"top of ROPS"
41 KY	002781524	87	fatal	pad	Yes	Yes <sup>n</sup>	edge	90	soil	ROPS crushed skull
42 KY	304289200	01	fatal	pad	Yes	Yes <sup>n</sup>	object	unk	soil	struck in head by overhead canopy
43 MD	127378016	96	nonfatal	smooth	Yes	defective	edge	unk	stone	pinned under "overhead protection"
44 MD	127378594	97	nonfatal	smooth	Yes	defective	soft area	90	soil	"overhead canopy," vibrator may have been on
45 MN	104558358	87	fatal	pad	Yes	Yes <sup>n</sup>	edge	90	soil	ROPS on arm
46 MO	FACE <sup>d</sup>	97	fatal	smooth	Yes	Yes <sup>n</sup>	edge	unk	asphalt	struck by ROPS
47 MT	100762657	89	fatal	pad	Yes	Yes <sup>n</sup>	edge	unk	soil	pinned by ROPS
48 NC	018576249	91	fatal	pad	Yes	No	edge	720	landfill	cab crushed
49 NC	111116166	95	fatal	pad	Yes	Yes <sup>n</sup>	edge	90	rock	"roll bar cage" above pinned victim
50 NC	111116257	94	fatal	smooth	Yes	1 of 2 <sup>n</sup>	edge	90	loading	struck by ROPS, 2 seats, 1 belt
51 NC	305747313	02	fatal	smooth	Yes	No	runaway	90	transport	head struck canopy support
52 NY	106161888	02	nonfatal	smooth	Yes	Yes <sup>n</sup>	soft area	90	soil	"top of ROPS" pinned head
53 OH	DOE <sup>e</sup>	02	none	smooth	Yes	Yes <sup>y</sup>	slope	90	soil	survived
54 OR	105201941	88	fatal	rubber	Yes	Yes <sup>n</sup>	runaway	90	transport	rear gravel box on victim
55 SC	302417621 <sup>f</sup>	99	fatal	smooth	Yes	No	edge	90	soil	cab, new, pinned under ROPS
56 TX	109448084	93	fatal	smooth	Yes	Yes <sup>n</sup>	turn	90	transport	"roof of cab" landed on victim
57 TX	302662770	00	fatal	pad	Yes	Yes <sup>y</sup>	soft area	90	soil	crushed by canopy "cross-beam"
58 WA	303218817	00	fatal	smooth	Yes	Yes <sup>n</sup>	edge	90	soil	ROPS on shoulder

NOTE: for NIOSH FACE reports see <http://www.cdc.gov/niosh/injury/traumaconstructface.html>

- a NIOSH FACE Report 95MN47
- b NIOSH FACE Report 2000-20
- c NIOSH FACE Report 97AK01
- d NIOSH FACE Report 97MO37
- e U.S. Department of Energy (2002)
- f NIOSH FACE Report 99SC03
- y seatbelt worn
- n seatbelt not worn

<b>Table 3. Use of the Haddon matrix to analyze the risk factors related to a compactor overturn injury</b>			
<b>Factor</b>	<b>Pre-event</b>	<b>Event</b>	<b>Post-event</b>
<b>Machine</b>	1. articulated steering 2. a 9-wheel rubber-tired roller 3. no ROPS or seatbelt	1. rolled about 190° 2. ballast dumped out	1. steering wheel and throttle controls crushed
<b>Environment</b>	1. non-paved road 2. ditch along road edge 3. company required seatbelt use when present 4. 4% road grade	1. soft sand/gravel edge 2. sunny 3. roadside ditch 6-feet deep	1. tire marks indicate sharp turn away from road edge
<b>Operator/ driver</b>	1. 21-year-old female 2. 20 minutes of training 3. 200 hours of experience 4. driving in reverse	1. head, shoulder, and arm pinned under machine	1. extricated by co-worker 2. permanent brain damage

## **Machine, Environmental, and Human Factors**

Machine, environmental, and human factors contributed to the 58 compactor overturn injuries described in the OSHA and FACE investigation reports analyzed in detail (*see* table 2).

### **Machine-Related Factors**

Of the 58 overturns, nearly half (27) related to the smooth-drum, with the remainder roughly divided between the pad-footed (15) and rubber-tired (13) compactors (fig. 5). The type of compactor in one case was unknown.

For the pad-footed compactor overturns, all but two occurred along a road or embankment edge. One other overturn was initiated by an obstruction and another by sinking soft soil. The circumstances related to one overturn were unknown. Eight of the rubber-tired compactor overturns occurred at a road or embankment edge, and another five occurred when a unit went out of control as a runaway because of either brake or gear-shifting defects. As for the smooth-drum compactor, 20 of the 27 overturns occurred along roadway or embankment edges, four were runaways, one was cornering too fast, one was initiated by sinking soft soil, and the cause of one was unknown.

In two cases, leaving a compactor vibrator engaged while stationary may have led to the settling of soil on one side of the unit, allowing it to drop at an angle and overturn. Research has also identified cases where articulation of a mobile unit with the jackknife pointed toward an edge presented a substantial overturn hazard. Three situations led to a hazard in articulated (prime mover and trailer) units. In one situation, the center of gravity of the prime mover and the trailer may have combined in the turned situation to lower the tip angle of the compactor. (In a turned position, the wheels are directed away from the center and may no longer support that portion of the vehicle.) In another situation, the unit's momentum may have aided a tripping situation for an overturn. In the third situation, when turning away from an edge, one set of wheels or drums pointed away from the edge while the other set pointed and moved toward the edge.

A sloshing effect can also be a factor in overturns. Water may be used as ballast in ballast bins or in drums, and water tanks are typically mounted on compactors as a source for spraying. This water or other liquid can slosh toward a slope causing a shift in the center of gravity of the unit.

In another case, an operator steered across a road, but the steering angle of the machine did not allow him to turn sharply enough to become parallel with the edge, and thus, he went over the edge.

More than half – 55% – of the compactors involved in the 58 overturns did not have ROPSs, including 93% of the rubber-tired ones. The lack of an ROPS was a risk factor for an injury. By

contrast, an ROPS in combination with a seatbelt offered a system of operator protection in the case of an overturn. However, two new compactors failed to have a seatbelt installed, and two other seatbelts were inoperable with a broken latch and a missing nut needed to secure the belt to the unit.

When a compactor was restricted to a 90° overturn, the severity of any injury was less. Two additional examples not investigated by OSHA indicated the value of ROPS (U.S. Department of Energy 2002). In one such overturn, the operator, who'd worn a seatbelt, walked away without serious injury (fig.6). This unit overturned because it was compacting a slope laterally rather than up and down the slope. In another case, a four-post ROPS is credited with saving the operator's life in another pad-foot single-drum overturn (Patterson 1987). The operator suffered no fractures and was released from the hospital.

## **Environmental Factors**

The most significant environmental factor contributing to compactor overturns was found to be working near an edge of a road or embankment (*see* fig. 5). The slope at which an overturn was initiated ranged from 12° to 45°, and some overturns occurred with abrupt drop-offs such as over a pavement edge. A compactor may extend over an edge, an edge may give way and sink, or an edge may be sloped so that other factors may accumulate so as to reach the tip angle of the unit. There were two cases in which a compactor sank on a deep asphalt pour that was still warm and caused a tipping situation.

Next in significance in this category were steep slopes and roadway curves, where gear-shifting problems or poor brakes led to runaways (fig. 7). Indeed, steep slopes and curves at the bottom of a roadway have combined to present an overturn hazard; notably, no pad-footed compactor experienced a runaway, perhaps because that type of compactor does not operate on smooth surfaces. Other conditions contributing to runaways included hitting soft soil areas that depress on relatively level land, turning too fast, and kinetic issues such as striking rocks or other obstructions in a roadway.

In connection with the environment, the type of operation was also associated with compactor overturns. In compacting soil, pad-footed and smooth-drum compactors predominate, because rubber-tired compactors are rarely used for this task. Driving a compactor from one location to another as a method of transport was also related to overturns, principally through runaway excursions.

Compacting roadway shoulders presented a risk because a shoulder is an edge. When a compactor attempted to stay off asphalt while compacting a shoulder, some overturns occurred where a shoulder wasn't wide enough. Asphalt compacting presented a risk at the road edge where the deep, hot mix sank under the compactor's weight and on slopes when runaway excursions occurred on the smooth surface.

Hazards during gravel compacting may be similar to those associated with shoulder work. Loading and unloading compactors from trailers posed hazards because of the lack of friction of a steel-drum on ramps, the sometime lack of adequate width to reach from one ramp to another, the occasional use of unstable boards as ramps, or unloading onto a slope where a runaway was possible after descending a ramp. Compacting stone may be hazardous because the stone can be slippery. Landfills present irregular and steep terrain.

## **Human Factors**

The most serious human factor was a lack of seatbelt use, or an operator's unbuckling a seatbelt during an overturn and attempting to jump. However, using seatbelts without an ROPS is a recognized crushing hazard also, and one individual was belted in while there was no ROPS. In an overturn without an ROPS, the operator's chance of survival depends on jumping clear of the overturn path. One victim was unable to jump because of a disability.

## Possible ROPS Design Defects

One argument against implementing an OSHA standard for ROPSs on compactors has been that ROPSs are a hazard, because Brickman and Barnett (1999) identified 11 cases in which an ROPS was the crushing agent in an overturn injury.

In this study of 58 cases, one ROPS design feature did emerge as a consistent safety issue. In five of the cases in which an ROPS was cited as the cause of a fatal injury, a canopy struck the operator. Canopies have typically been used for shade, but have been adopted in some cases as part of ROPS design. Other cases of individuals struck by ROPSs did not contain enough information to determine the part of the structure that struck the victim. The number of incidents may have been higher than the 5 incidents identified, because a falling or jumping operator would likely move in the direction of the canopy during a rollover.

Every ROPS-equipped compactor considered in this study of 58 cases was restricted to a 90° overturn, except one. The exception was a 1972 model landfill pad-foot compactor with an atypical tricycle design that overturned, crushing the cab, and killing the operator. The compactor overturned twice (720°), with the cab offering little resistance to the overturn, thus making it ineffective as an ROPS.

In another case of a fatal overturn in an ROPS-equipped compactor, there was a design problem: the seat was situated to the side for improved edge viewing but rendered the unit more awkward to steer, especially in a runaway situation (fig. 8). (The compactor was not equipped with a seatbelt.)

## Seatbelt Effectiveness

Seatbelts appear to prevent injuries as a result of collisions or potential falls from an ROPS-equipped compactor. Several cases included runaway units that did not overturn, but from which operators fell or jumped and were injured by the impact of the fall. An ROPS-seatbelt combination might have prevented injuries, if a seatbelt had been used. Other situations involved collisions with either off-highway or highway vehicles in which a seatbelt likely would have saved lives. The victims in the two collisions that did not involve overturns were thrown off a compactor by the force of a collision and killed by the impact of the crash.

Several factors led to the problem of seatbelt non-use. Among these were the failure of an operator to use a belt (possibly because of discomfort or seatbelt malfunction), unfastening a belt during a runaway excursion or overturn as a panic response, the lack of a seatbelt with an ROPS, the presence of a seatbelt when an ROPS was not present, and dependence upon a cab as a restraint system.

If cabs are used as restraints, instead of seatbelts, the doors must be closed. Three cases involved cabs. One was a case of a non-crush-resistant cab, which was discussed above. The other two cases involved operators who had a cab door open and, during an overturn, each operator was unrestrained, falling through the door and being crushed by the cab frame. The Scandinavians have adopted enclosed cabs as their restraint device (Myers 2000), but the door needs to be closed to restrain the operator in the event of an overturn.

## OSHA Enforcement

Until the early 1990s, OSHA typically excluded overturns from ROPS-related citations, because a standard was not in force. However, some jurisdictions and states used OSHA's General Duty Clause to cite employers who failed to provide a workplace free of the overturn hazard. In addition, compliance officers used the clause to cite employers for not requiring the use of a seatbelt in the presence of an ROPS. The OSHA 1998 directive (Swanson) provides for consistency in citing the lack of an ROPS as a violation under the clause. Six compactor-overturn cases were cited as General Duty Clause violations between 1999 and 2002.

## Discussion and Recommendations

Workers continue to die and suffer injury from overturns of compactors lacking ROPSs more than 30 years after the passage of the Occupational Safety and Health Act of 1970, which established OSHA. The problem has long been recognized.

As long ago as 1974, in his report to OSHA, Woodward felt compelled to offer insight – albeit unsolicited – into a myth of compactor safety:

The number of deaths and injuries attributed to the overturn of asphalt rollers would seem to indicate the improbability of designating “safe” work practices for the seven types of vehicles studied in this program. Asphalt rollers are almost always used on flat level road sections with small grade changes. They are never used off the highway bed in rocky, uneven terrain (like a dozer is), never used at a high speed with heavy loads (like a scraper is), never used in a manner to radically change their center of gravity (like a loaded front-end loader), never even used in the relatively shallow sloping angles that a motor grader experiences. A description of the work practices of a roller would seem, on paper, to indicate work conditions that are very unlikely to allow roll-overs. But rollers do overturn! And operators are injured and killed.

Several recommendations are offered as a result of this study.

- OSHA should promulgate a standard that requires ROPSs and seatbelts on all compactors (rollers) where employers are covered by the OSHA Act. This standard should extend beyond the construction sector and should include public employees in state OSHA plans. In the interim, OSHA should establish a special-emphasis program that cites the lack of an ROPS and seatbelt on compactors (and all off-highway vehicles) as a violation of the General Duty Clause.
- The U.S. Department of Labor’s Advisory Committee on Construction Safety and Health should consider recommending an emergency temporary standard to OSHA that requires the installation of ROPSs and seatbelts on compactors (rollers).
- All compactors (or rollers) an ROPS should either be retrofitted with an ROPS and seatbelt or scrapped.
- Training procedures for the safe operation of compactors (rollers) are needed. These procedures need to deal with the safety of an extra rider on the vehicle during instruction. The training of operators as established by the manufacturer should include the following:
  - proper uses of a compactor (for instance, roll slopes perpendicularly and not laterally)
  - the presence of an ROPS
  - mandatory presence of (and use of) operational seatbelts
  - procedures for runaway prevention and actions in case of a runaway
  - stability factors of the vehicle including knowledge of its tip angle, the effect on the tip angle of adding ballast, the static and dynamic effect on the center of gravity of articulating the vehicle, and its inherent instability as compared to other vehicles
  - environmental hazards, including slopes, edges, obstructions, hot asphalt at the edges, soft soil pockets, and the lack of friction on rock surfaces
  - the need to properly maintain the vehicle-braking system.
- Research is needed into how to prevent the overturn-related crushing of an operator by the canopy portion of an ROPS in the event of a seatbelt failure or a failure in to use a seatbelt.
- Vibratory compactors should be designed to automatically disengage (from dynamic to static mode) when an operator stops a vehicle.
- Articulated vehicles should be designed for stability in any operational position.
- Vehicles with ROPS cabs should be designed to operate only when the door is shut
- Trailers with loading ramps should be used when transporting compactors so the ramps can accommodate the width of the compactor and assure adequate friction to avoid slipping or skidding.
- Padding on the interior of the ROPS is needed to protect against head injury during overturns.



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## Annex A: Figures 1 - 8



**Figure 1.** A double smooth-drum compactor with an ROPS canopy and articulated steering.



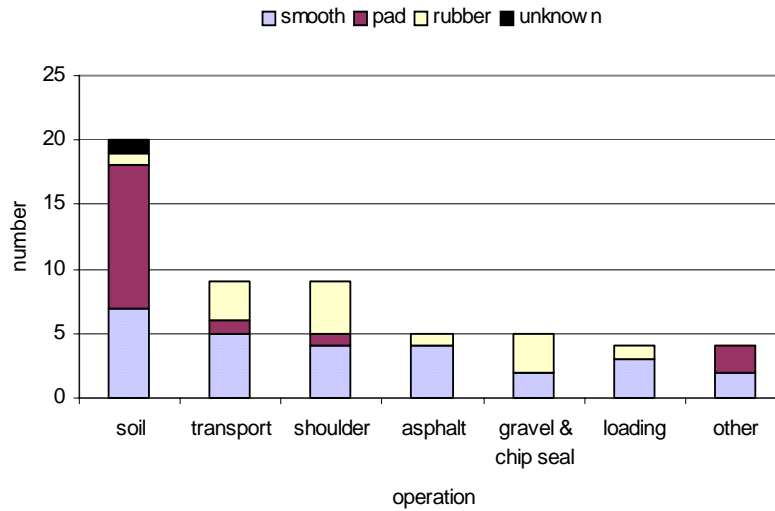
**Figure 2.** A pad-foot compactor with a single drum and articulated steering.



**Figure 3.** A rubber-tired compactor with a two-post ROPS.



**Figure 4.** A double drum pad-foot compactor with articulated steering and a four-post ROPS with a canopy.



**Figure 5.** Number of compactor overturns resulting in operator injury, by conditions and type of compactor, 1985-2002

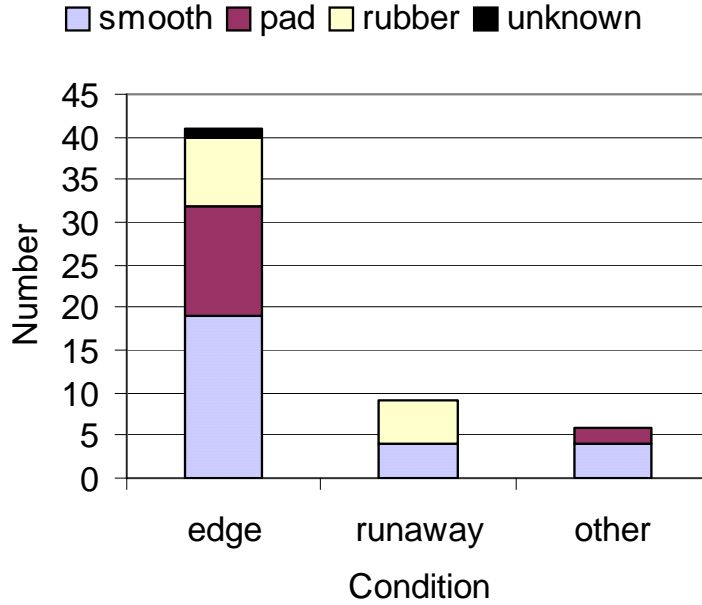
*Note:* 56 cases

*Source:* Based on OSHA and NIOSH reports



**Figure 6.** A compactor overturn that shows the anti-roll function of an ROPS

*Source:* U.S. Department of Energy



**Figure 7.** Conditions contributing to overturns, by type of compactor and number of overturn incidents, 1985-2002

*Source:* Based on OSHA and NIOSH reports



**Figure 8.** A seat and steering wheel perpendicular to the front of a compactor, which has no seatbelt; this unit was involved in an overturn-related death

*Source:* North Carolina Department of Labor

## **Annex B: The Usefulness of OSHA and NIOSH Reports for This Research**

Unless a researcher had the OSHA inspection number or the employer's name, it was nearly impossible to access OSHA files through the Freedom of Information Act. Issues related to using the OSHA reports fell into two categories: (1) different policies between state and federal programs and the lack of record retention and (2) the exclusion of inspection information that was critical to identifying risk factors.

The reports were available from OSHA through two approaches. One approach was to request all reports by investigation number within ten federal regions. The other approach was to request the reports from the OSHA Area Office (in federal jurisdictions) or state OSHA agency (in state jurisdictions). To protect confidentiality, OSHA Accident Reports were provided with all names expunged from the reports, except decedents and officials representing the employers.

Federal policy is to retain reports related to fatalities indefinitely and to destroy other reports after seven years of retention. However, state programs have a variety of retention rules. For example, California destroys all reports after three years, and other states have report retention rules that fall somewhere between the California and federal policies. Nonetheless, many federal offices could no longer locate older fatality reports, which typically had been sent to archives. Some were lost and some were destroyed.

The California policy was particularly problematic. OSHA did not post its report summaries on the Internet until four to five years after the incident because it has a process of evaluating and editing the summaries before they were posted. By the time the California cases were searchable on the Internet, the original reports had been destroyed.

In addition, OSHA policy is to protect the privacy of individuals named in the reports. Thus, names other than the company officials and the decedent were typically marked out. However, policy varies broadly in excluding other information based upon additional criteria such as interagency memoranda and government agent opinions. In the case of the Oklahoma Area Office, nearly all information based upon the field notes was struck out since it was judged to be "opinion," as were typed narratives, sketches of the scene, whole witness statements (without their names and other personal identifiers), and manufacturer information, etc., all of which could assist in identifying risk factors. In addition, Kansas has a privacy law that precluded the release of any inspection report information and is the antithesis of an open records doctrine.

Conversely, a lot of information that was released proved helpful. Some compliance officers were detailed in naming the make and model of units, and though more rarely, the machine's hour meter reading. Photographs were invaluable in examining the terrain and the type of machine—whether compactor or trailer—involved in the incident. Some OSHA reports included a handwritten record of "fatal facts," which was useful and provided consistency between the risk factors reported from one report to another. Especially detailed were the reports from the North Carolina state program. The Portland Area Office assisted in identifying additional and more recent cases that had yet to be posted on the Internet. In one case, the compliance officer reviewed the employer's accident log and discovered three additional compactor overturns in which no serious injury occurred.

Police reports enclosed with the reports were also useful, for they typically included precise measurement of slopes and distances. Police reports also detailed witness statements and observations regarding the part of the machine that struck the victim.

The NIOSH FACE reports were helpful because they used much of the same information that was applied in the Haddon matrix. However, they did not cite the OSHA investigation report, which was problematic in producing a consistent file on each case. Although some FACE reports detailed the machine involved in the incidents including photographs, other reports' authors appeared reluctant to name the make and model of the machine. In determining risk factors, this information was critical from the viewpoint of identifying engineering solutions to the injury risks.

One jurisdiction that was likely undercounted was the government sector. Some state programs, such as North Carolina, aggressively regulate state and local government sectors. Also, some OSHA Area Offices, such as Portland, actively investigate federal agencies. In North Carolina, where the state investigates state and local government employers that are outside federal jurisdiction, seven overturn incidents were investigated and three (43%) of them involved either city or state employees. Since most of the government sectors were unregulated, investigating these omitted sectors may be a role for NIOSH's FACE program to