Falls through Roof and Floor Openings and Surfaces, Including Skylights: 1992–2000

Thomas G. Bobick, P.E.[1]

Abstract: Fall-related occupational injuries and fatalities are still serious problems in the U.S. construction industry. Two Bureau of Labor Statistics databases—Census of Fatal Occupational Injuries and Survey of Occupational Injuries and Illnesses—were examined for 1992–2000. An important subset of falls-to-lower-level incidents is when workers fall through openings or surfaces, including skylights. A total of 605 fall-through fatalities occurred during 1992–2000. Also, 21,985 workers were injured seriously enough from fall-through incidents to miss a day away from work (DAFW). Fall-through injuries are among the most severe cases for median number of DAFW. Median DAFW were 35, 11, 25, 12, and 36 for fall-through roof and floor openings, roof and floor surfaces, and skylights, respectively, compared to 10 DAFW for all fall-to-lower-level incidents in all U.S. private industry. A conservative approach, which assumes that direct and indirect costs are equal, estimates a range of $55,000–$76,000 for the total cost of a 1998 DAFW fall-through injury. Current work practices should use commercial fall-prevention products to reduce the frequency and costs of fall-through incidents. These analyses have identified a subset of fall-related incidents that contribute to excessive costs to the U.S. construction industry. Researchers can use a systems approach on these incidents to identify contributing risk factors. Employers and practitioners can alert managers and work crews about these dangerous locations to eliminate these hazards that are often obvious and easy to rectify.

DOI: 10.1061/(ASCE)0733-9364(2004)130:6(895)

CE Database subject headings: Construction site accidents; Fatalities; Injuries; Cost estimates; Occupational safety.

Introduction

The British Health and Safety Executive states quite succinctly that "roof work is dangerous" (HSE 1998). Early research conducted by Parsons and Pizatella (1984) with the Division of Safety Research (DSR) of the U.S. National Institute for Occupational Safety and Health (NIOSH) described the construction industry as a "work environment subject to continuous change." That is still currently true. Parsons et al. (1986) and Personick (1990) indicated that the construction industry, and roofers and slaters in particular, had elevated fatality and injury rates. That is also still true. "Fall from elevation" was identified to be the leading cause of death and the second leading cause of injury after "burns from hot materials" to roofers and slaters (Parsons et al. 1986). Work-related falls are still a major cause of death and serious injury throughout the United States decades later.

Job-related falls contribute to hundreds of deaths and tens of thousands of serious injuries every year. During the years 1992–1999, a total of 50,004 U.S. workers died on the job, of which 5,368 (10.7%) died from a fall-related event. From 1992 through 1999, the fall-at-work category was the fourth leading cause of death for workers in all U.S. industries [behind transportation incidents (41.6%), assaults and violent acts (18.7%), and contact with equipment and objects (16.0%)] [Bureau of Labor Statistics (BLS) 2001b, pp. 37–38]. An analysis conducted by NIOSH/DSR (Braddee et al. 2000) of occupational fatalities that occurred in the U.S. during the years 1980 to 1994 reported similar findings. Kisner and Fosbroke (1994) indicated that the leading cause of death to U.S. construction workers during 1980–1989 was falling (25.4%). A study by Kines (2001) indicated that "fall from heights" contributed to 23% of all construction-related fatalities in Denmark during 1993–1999.

Fatal falls occur every year in each of the nine major Divisions of private industry, as defined in the Standard Industrial Classification (SIC) Manual (Office of Management and Budget 1987). During the period 1992–2000, more than 50% of all fall-related deaths occurred in the Construction Division, whereas during the same years, only 11% of the fall-related fatalities occurred in the Services Division, and 9% of the fall-related fatalities occurred in the Manufacturing and the Agriculture–Forestry–Fishing Divisions.

Work-related falls, including falls-on-the-same level, accounted for 16.4% of all serious injuries that occurred in U.S. private industry in 1993 (BLS 1996b). Serious injuries are described by BLS as those that cause at least one day away from work (DAFW) beyond the day the incident occurred. The falls category was exceeded only by "bodily reaction and exertion" and "contact with objects and equipment" for frequency of DAFW injuries in 1993.

Of the three industrial sectors that comprise the Construction Division (SIC Major Groups 15, 16, and 17), the General Building contractors (SIC Major Group 15) and the Special Trade contractors (SIC Major Group 17) typically have an elevated exposure to fall-related injuries and fatalities when compared to the

[1]PhD, CSP, Research Safety Engineer, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health, Division of Safety Research, 1095 Willowdale Rd., Mailstop H-G800, Morgantown, WV 26505-2888. E-mail: txb4@cdc.gov

Note. Discussion open until May 1, 2005. Separate discussions must be submitted for individual papers. To extend the closing date by one month, a written request must be filed with the ASCE Managing Editor. The manuscript for this paper was submitted for review and possible publication on July 31, 2003; approved on February 24, 2004. This paper is part of the ***Journal of Construction Engineering and Management***, Vol. 130, No. 6, December 1, 2004. ©ASCE, ISSN 0733-9364/2004/6-895–907/$18.00.

Heavy Construction contractors (SIC Major Group 16). Part of the General Building Major Group is Residential Building construction (SIC Code 152) and Nonresidential Building construction (SIC Code 154), which includes both commercial and industrial construction. Workers in these two Groups are exposed to a variety of potential fall-to-lower-level hazards. In the Special Trade Major Group, the Roofing, Siding, and Sheet metal contractors (SIC 1760) and Structural Steel Erection contractors (SIC 1791) have to perform tasks that routinely expose workers to fall-related hazards. Other trades, such as contractors in Masonry and other stonework (SIC 1741), Painting and paper hanging (SIC 1720), and Carpentry (SIC 1751) also conduct tasks that expose workers to potential falls to a lower level, but not to the same extent as roofers and steel erectors.

The writer's analysis of the BLS *Annual Survey* for 1997 (BLS 1999c, p. 420) revealed that the median number of DAFW for "all types of falls" was 8 days for all U.S. private industry. Median number of DAFW for "falls-to-lower level" for U.S. private industry in 1997 was 12. However, the median number of DAFW for a "fall-through roof opening (RO)" was 60 days. Because of the extremely high median values of DAFW for fall-through incidents, a decision was made to conduct a detailed analysis of these types of injury incidents.

The objective of this current study was to compile descriptive statistics (frequency and severity) related to incidents that involve workers falling *through* either an opening or some type of surface. Falls *from* a roof or *from* the leading edge are not included in this analysis. This analysis includes only fall-through incidents, which are described by the BLS to have occurred through: (1) An existing floor opening (FO), (2) an existing RO, (3) an existing floor surface (FS), (4) an existing roof surface (RS), or (5) an existing skylight (SL) fixture.

A note of explanation is needed here. Employers are required to protect workers from potential fall-through incidents by regulations from the Occupational Safety and Health Administration (OSHA), specifically 29 CFR (Code of Federal Regulations) Sec. 1910.23 for General Industry and 29 CFR Sec. 1926.500, Subpart M for the Construction Industry. Descriptions used in the BLS data books differ from these OSHA regulations. A "hole" is defined in 29 CFR Sec. 1926.500(b) as "a gap or void 2 in. (5.1 cm) or more in its least dimension, in a floor, roof, or other walking/working surface," and an "opening" is defined (in the same section) as "a gap or void 30 in. (78 cm) or more high and 18 in. (48 cm) or more wide, in a wall or partition, through which employees can fall to a lower level." According to the OSHA regulations, a hole occurs only in a floor or roof. This differs from the listings in the BLS publications. However, since the focus of this study is to analyze the BLS data, the standardized descriptions used in the BLS publications (listed above as FO, RO, FS, RS, and SL) are also used in this analysis.

Methods

Fatal Injuries

Analysis of fatal incidents was conducted using the BLS Census of Fatal Occupational Injuries (CFOI) data for the years 1992 through 2000 (BLS 1994, 1995b, 1996a, 1997a, 1998b, 1999b, 2001b, 2002b). The years 1992–2000 were chosen because the CFOI database was initiated in 1992, and the year 2000 was the most current data when this compilation was started. CFOI is administered by BLS, along with participating State agencies. CFOI collects data from U.S. private industry, all government agencies (federal, state, and local), and from self-employed contractors.

Data on work-related fatalities are compiled from various Federal and State administrative sources, such as death certificates, workers' compensation reports and claims, reports to regulatory agencies, medical examiner reports, police reports, and news reports (BLS 1999b). More than 30 data elements are collected and coded, including information about the worker, circumstances of the fatal incident, and nature of the fatal injury. At least two independent source documents are typically required to verify the work relatedness of the fatal injury. CFOI states that counts of occupationally related fatalities are "as complete and accurate as possible." (BLS 1999b, p. 2).

Two limitations associated with CFOI data that may contribute to minor discrepancies in the data compiled from the CFOI reports are: (1) "States are allowed a [one] time revision, one year after the initial total is published. This allows additional cases, identified after the initial publication deadline, to be included in the final (revised) total." (BLS 2001b), and (2) fatality data are reported in the source documents as percentages of corresponding totals. The first limitation may have inadvertently occurred if the revised totals were not always used to develop specific category counts, and the second limitation may contribute to minor errors when choosing an integer value from a percentage calculation.

Serious Injuries

Analysis of "DAFW" incidents utilized data from the BLS Annual Survey of Occupational Injuries and Illnesses for the years 1992 through 2000 (BLS 1995a, 1996b, 1997b, 1998a, 1999a, 1999c, 2001a, 2002a,c). This is an estimate of values based on a two-stage sample of approximately 250,000 U.S. business establishments (i.e., private industry only) (stage 1) during the years 1992–1994 (BLS 1995a, 1996b, 1997b), and approximately 180,000 to 169,000 U.S. business establishments during the years 1995–1998 (BLS 1998a, 1999a,c, 2001a). The number of establishments sampled for 1999 and 2000 were not available from the BLS website. Original and follow-up mailings resulted in a response rate that varied from 90% to 93% across the seven years (BLS 1995a, 1996b, 1997b, 1998a, 1999a,c, 2001a). From the selected establishments (stage 1), approximately 550,000 "injuries and illnesses with days away from work (stage 2) were used to obtain demographic and detailed case characteristic information" (BLS 1995a) for 1992–1994. However, for 1995 to 1998, the second-stage sample of DAFW incidents that were used to compile similar pertinent detailed worker and incident information declined from 430,000 to 254,000 (BLS 1998a, 1999a,c, 2001a). Note that during the five years from 1994 to 1998, there was a decrease in the number of business establishments that were sampled (from 250,000 to 169,000). Because of the change in business establishments that were sampled from year to year, the number of incidents in some fall-through categories also changed quite dramatically from one year to the next. This was especially true for frequency and severity data related to DAFW incidents caused by falls through SLs, as shown in Table 9.

For the DAFW incidents, the Annual Survey provides seven missed-day categories—1 day, 2 days, 3 to 5, 6 to 10, 11 to 20, 21 to 30, and 31 or more days missed because of a severe injury. To develop an estimate of the total number of days that were actually missed from work, the number of cases in each of the seven categories of missed days were multiplied by the value for that respective category. The number of cases in the "one" or "two"

J. Constr. Eng. Manage., 2004, 130(6): 895-907

Table 1. Proportion of U.S. Occupational Fatal Injuries Caused by Falls and Falls to Lower Level, 1992–2000[a]

Year	Total U.S.[b] occupational fatal injuries	Total U.S.[b] fatal falls (% of column 2)	Total U.S.[b] fatal falls to lower level (% of column 3)	Fatal injuries, only private industry (% of column 2)	Fatal falls, only private industry (% of column 5)	Fatal falls to lower level, private industry (% of column 6)
1992	6,217	600 (9.6)	507 (84.5)	5,497 (88.4)	552 (10.0)	N.A.[c]
1993	6,331	618 (9.8)	534 (86.4)	5,643 (89.1)	570 (10.1)	N.A.[c]
1994	6,632	665 (10.0)	580 (87.2)	5,959 (89.8)	620 (10.4)	551[d] (88.9)
1995	6,275	651 (10.4)	578 (88.8)	5,495 (87.6)	621 (11.3)	554[d] (89.2)
1996	6,202	691 (11.1)	610 (88.3)	5,597 (90.2)	660 (11.8)	584[d] (88.5)
1997	6,238	716 (11.5)	653 (91.2)	5,616 (90.0)	688 (12.2)	620[d] (90.1)
1998	6,055	706 (11.7)	625 (88.5)	5,457 (90.1)	682 (12.5)	606[e] (88.9)
1999	6,054	717 (11.8)	634 (88.4)	5,488 (90.6)	683 (12.4)	617[e] (90.3)
2000	5,915	734 (12.4)	659 (89.8)	5,344 (90.3)	704 (13.2)	636[c] (90.3)
Total	55,919	6,098 (10.9)	5,380 (88.2)	50,096 (89.6)	5,780 (11.5)	4,168[f] (89.5)[f]

[a]Source: CFOI = Census of Fatal Occupational Injuries, Bureau of Labor Statistics, Department of Labor.

[b]Total U.S. includes private industry + all government sources + self-employed contractors.

[c]N.A. = data not available for these two years.

[d]These values have been estimated from the CFOI data tables that list incident event for major private industry divisions.

[e]The CFOI data tables for 1998 and 1999 provide a separate listing for fatalities caused by falls-to-lower level.

[f]This total and (average proportion) are based on 7-years of data only; note: the (average proportion) is not related to column 6.

missed-days category was multiplied by one or two. The next four categories were multiplied by the midpoint of each range (4, 8, 15.5 and 25.5, respectively). The middle value of each of these four ranges was used to calculate the total number of days missed because cases were assumed to be uniformly distributed across all values in each range. For example, in the 11 to 20 DAFW category, it would be equally likely for any of those ten values to occur. Twelve missed days is as likely to occur as 17 missed days since these are independent random events. One value would not be expected to occur more often than any other value. So, the midpoint of that category (15.5) is multiplied by the frequency count for that interval to obtain the estimated total number of DAFW in that particular interval. The case distribution for the ⩾31 category could not be determined because of the lack of an endpoint for the category. Thus, a conservative estimate of only 31 days was applied to each case in that category. The conservative nature of this estimate is evidenced by the fact that in many cases (14 of 45) reported in Table 9, the median days missed, which is listed in brackets [ ], is indeed greater than 31, and as high as 70 or 72 for the number of DAFW in Table 9. Because of these two assumptions (i.e., uniform distribution for four of the categories, and assigning only 31 missed days to the last category), the total calculated numbers of DAFW are more of a reasonable estimate than a definitive total. However, because the assumptions were applied equally across all nine years (1992 to 2000) and to all five fall-through work site categories (listed in Table 9), the resulting totals provide an indication of the relative contribution of the five different categories to the overall frequency and severity of the fall-through problem.

Data

Fatal Injuries

Between 1992 and 2000, 55,919 individuals were killed at work in the U.S. (Table 1). This total is the combination of private industry, government agencies (federal, state, and local), and self-employed contractors. Table 1 presents yearly totals of U.S. fatal falls (of all types) and U.S. fatal falls to a lower level. During the nine years, a total of 6,098 U.S. workers (10.9% of total) were killed by falling, either on same level or to lower level. Of the 6,098 fatalities, 5,380 (88.2%) U.S. workers (private industry, government, self-employed) were killed when falling to a lower level. Table 1 also lists private industry fatalities, including fall-related deaths. Private industry accounted for 89.6% of all U.S. occupational fatalities for 1992–2000, and 94.8% of all fall-related fatalities (5,780 of 6,098).

Table 2 presents data for 1992–2000 for falls to a lower level in all U.S. workplaces, and for a subset of fatalities that involves falls through ROs or FOs or through RSs or FSs, including existing SLs. Because of BLS confidentiality requirements related to minimal category counts, data for RSs and FSs were combined, resulting in four separate categories in Table 2.

For 1992–2000, the yearly occurrence of fall-to-lower-level fatalities has increased from 507 to 659 (Table 2). Since 1993, the number of workers killed by a fall-through event has ranged between 57 and 77 per year. Of 605 fatal fall-through incidents, 282 fatalities (46.6%) involved openings, 150 (24.8%) involved existing SLs, and 173 (28.6%) involved RSs and FSs (Table 2).

Fatal injury data for the private sector construction industry are presented in Table 3. The proportion of fatal injuries in private sector construction increased from 16.7% (919) to 21.6% (1,154) for 1992–2000 (Table 3). Overall, fall-related fatalities accounted for 31.8% of private construction deaths. Also, over the nine years, 53% of fatal falls in U.S. private industry occurred in construction.

Of the fall-related fatalities in private construction during 1992–2000 (Table 4), 22.3% occurred in General Building (SIC 15), 7.5% occurred in Heavy Construction (SIC 16: bridges, roads, etc.; SIC 16 is not listed in Table 4), and 70.1% occurred in Special Trades (SIC 17). These values agree with an OSHA study (Culver and Connolly 1994) of fatal falls for 1985–1993 that found the percent distribution for SIC 15, 16, and 17 to be 17%, 11%, and 72%, respectively

J. Constr. Eng. Manage., 2004, 130(6): 895-907

Table 2. Selected U.S. Occupational Fall-Related Deaths, 1992–2000[a]

Year	Total U.S.[b] fatal falls to lower level	Total U.S.[b] fall-through cases (% of total fatal falls to lower level)	Fall-through existing roof opening	Fall-through existing floor opening	Fall-through skylight fixture	Fall-through roof and floor surfaces
1992	507	41 (8.1)	8	11	10	12
1993	534	66 (12.4)	6	24	19	17
1994	580	57 (9.8)	11	14	14	18
1995	578	73 (12.6)	18	16	18	21
1996	610	66 (10.8)	15	13	16	22
1997	653	77 (11.8)	20	20	17	20
1998	625	77 (12.3)	12	21	22	22
1999	634	74 (11.7)	14	19	18	23
2000	659	74 (11.2)	15	25	16	18
Total	5,380	605 (11.2)	119	163	150	173

[a]Source: CFOI = Census of Fatal Occupational Injuries, Bureau of Labor Statistics, Department of Labor.

[b]Total U.S. includes private industry + all government + self-employed contractors.

Two subgroups of SIC 15 are Residential Building (SIC 152) and Nonresidential Building (industrial and commercial) (SIC 154). In CFOI, SIC 17 is composed of 16 subgroups of work activities, ranging from plumbing and roofing to carpentry and excavation work. These 16 subgroups were analyzed for fall-related fatalities, with the top five listed in Table 4. Across the nine years, these five trades account for 1,514 of the 2,148 (70.5%) fall-related fatalities that occurred in SIC 17.

For 1992–2000, roofing, siding, and sheet metal work (SIC 176) had the most fall-related deaths ($n=574$), followed by structural steel erection (SIC 1791; $n=322$) (Table 4). Thus, each year, an average of 64 workers died from falling while working in the roofing, siding, and sheet metal industry, and an average of 36 workers died from falling while erecting structural steel. The other three trades in Table 4 are listed since fall-related deaths in those trades amounted to about 50% of their total deaths.

Fatality rates were not reported in CFOI data in 1992 or 1993. For 1994–2000, fatality rates (for all causes) in U.S. private industry decreased from 5.7 to 4.6 deaths per 100,000 workers (Table 5). In construction, fatality rates (all causes) have decreased across the seven years, from 14.8 to 12.9 deaths per 100,000 construction workers (Table 5). Fatality rates for roofers (all causes) remained elevated in 1994–2000 (except for 1998), ranging between 27.5 and 31.0 deaths per 100,000 roofers.

Fall-related fatality rates for all U.S. private industry (1994–2000) have remained steady at 0.6 deaths per 100,000 U.S. workers. Fall-related fatality rates in construction decreased slightly from 4.8 to 4.2 deaths per 100,000 construction workers for 1994–2000 (Table 5). Despite the decrease, the average fall-related fatality rate in construction (1994–2000) is more than $7\frac{1}{2}$ times greater than the national-average fall-related fatality rate in private industry (4.6 versus 0.6 deaths per 100,000 workers). The fall-related fatality rate for roofers has a 7-year average of 20.9 deaths per 100,000 roof workers. This roofer fall-related fatality rate is $4\frac{1}{2}$ times greater than the fall-related fatality rate for the construction industry, and 35 times greater than the fall-related fatality rate for all U.S. private industry.

Serious Injuries

An injury is described by BLS as serious when the worker misses at least one full day of work beyond the day the incident occurred

Table 3. Proportion of U.S. Private Industry Fatal Injuries Caused by All Events in Private Construction, and by Fall-Related Events in Private Construction, 1992–2000[a]

Year	Fatal injuries, private industry	Fatal injuries, construction industry (% of column 2)	Fatal falls, construction industry (% of column 3)	Construction fatal falls as a % of private industry fatal falls (table 1, column 6)
1992	5,497	919 (16.7)	267 (29.0)	48.4
1993	5,643	932 (16.5)	273 (29.3)	47.9
1994	5,959	1,028 (17.2)	330 (32.1)	53.2
1995	5,495	1,055 (19.2)	337 (31.9)	54.3
1996	5,597	1,047 (18.7)	337 (32.2)	51.1
1997	5,616	1,107 (19.7)	377 (34.1)	54.8
1998	5,457	1,174 (21.5)	384 (32.7)	56.3
1999	5,488	1,190 (21.7)	379 (31.8)	55.5
2000	5,344	1,154 (21.6)	374 (32.4)	53.1
Total	50,096	9,606 (19.2)	3,058 (31.8)	52.9

[a]Source: CFOI = Census of Fatal Occupational Injuries, Bureau of Labor Statistics, Department of Labor.

J. Constr. Eng. Manage., 2004, 130(6): 895-907

Table 4. Proportion of Fall-Related Fatalities for Selected Portions of the Private Sector Construction Industry, 1992–2000[a]

Year	Total fatal falls, construction industry	General building (SIC 15) (% of column 2)	Residential building (SIC 152)	Nonresidential building (SIC 154)	Special trades (SIC 17) (% of column 2)	Roofing, siding, and sheet metal (SIC 176)		Structural metal erection (SIC 1791)		Masonry, stone work, tile setting, and plastering (SIC 174)		Painting and paper hanging (SIC 172)		Carpentry and floor work (SIC 175)	
						(*n*)	(%)[b]	(*n*)	(%)[b]	(*n*)	(%)[b]	(*n*)	(%)[b]	(*n*)	(%)[b]
1992	267	62 (23.2)	Not available	Not available	182 (68.2)	47	(58.8)	34	(81.0)	11	(35.5)	20	(52.8)	20	(55.6)
1993	273	57 (20.9)	26	24	187 (68.5)	56	(66.7)	27	(65.9)	20	(48.8)	22	(57.5)	13	(31.6)
1994	330	79 (23.9)	27	46	231 (70.0)	60	(67.4)	36	(69.2)	28	(52.8)	25	(62.5)	17	(54.8)
1995	337	79 (23.4)	40	38	232 (68.8)	66	(68.4)	29	(70.7)	31	(47.0)	20	(42.6)	21	(55.3)
1996	337	82 (24.3)	34	43	230 (68.2)	65	(65.7)	42	(76.4)	24	(46.2)	28	(68.3)	17	(47.2)
1997	377	78 (20.7)	31	44	271 (71.9)	74	(71.2)	36	(75.0)	21	(50.0)	24	(53.3)	24	(52.9)
1998	384	89 (23.2)	48	36	271 (70.6)	65	(71.4)	43	(75.4)	28	(52.8)	19	(45.2)	26	(61.9)
1999	379	79 (20.8)	36	41	277 (73.1)	72	(72.0)	40	(71.4)	27	(47.4)	22	(61.1)	24	(52.2)
2000	374	76 (20.3)	40	33	267 (71.4)	69	(70.4)	35	(70.0)	35	(53.8)	24	(53.3)	27	(46.6)
Total (9 year avg)	3,058	681 (22.3)	282+[c]	305+[c]	2,148 (70.2)	574	⟨68.0⟩[d]	322	⟨72.8⟩[d]	225	⟨48.3⟩[d]	204	⟨55.2⟩[d]	189	⟨50.9⟩[d]

[a]Source: CFOI = Census of Fatal Occupational Injuries, Bureau of Labor Statistics, Department of Labor.

[b]This (%) is the proportion of the total number of fatal injuries in that year that were fall-related in that trade. For example, in 1992, a total of 80 fatal injuries occurred in SIC 176, of which 47 (=*n*) or (58.8%) where fall related. Thus, (47) ÷ (0.588) = 80 total.

[c]These two totals are 8-year totals only since 1992 values were not reported by BLS.

[d]Values in the angular brackets ⟨ ⟩ are overall averages for the 9 years.

J. Constr. Eng. Manage., 2004, 130(6): 895-907

Table 5. Frequency and Rate of Fatal Injuries (*from All Causes, and Fall-Related Causes*) for U.S. Private Industry, the Construction Industry, and Roofer Occupation, 1994–2000[a]

Year	1994	1995	1996	1997	1998	1999	2000	7-year average
Private industry fatalities								
Total frequency	5,959	5,495	5,597	5,616	5,457	5,488	5,344	5,565
Fall-related frequency	*618*	*625*	*659*	*688*	*682*	*683*	*704*	*666*
Employment (in thousands)	104,754	106,522	108,472	111,417	113,688[b]	114,333[b]	116,174[b]	110,766
All-cause rate[c]	5.7	5.2	5.2	5.0	4.8	4.8	4.6	5.0
Fall-related rate[c]	*0.59*	*0.59*	*0.61*	*0.62*	*0.60*	*0.60*	*0.61*	*0.60*
Construction industry fatalities								
Total frequency	1,028	1,055	1,047	1,107	1,174	1,190	1,154	1,108
Fall-related frequency	*330*	*337*	*337*	*377*	*384*	*379*	*374*	*360*
Employment (in thousands)	6,948	7,153	7,464	7,844	8,097[b]	8,500[b]	8,946[b]	7,850
All-causes rate[c]	14.8	14.7	14.0	14.1	14.5	14.0	12.9	14.1
Fall-related rate[c]	*4.8*	*4.7*	*4.5*	*4.8*	*4.7*	*4.5*	*4.2*	*4.6*
Roofer fatalities								
Total frequency	53	60	61	55	50	59	65	58
Fall-related frequency	*38*	*45*	*41*	*41*	*39*	*51*	*48*	*43*
Employment (in thousands)	180	205	197	200	242[b]	214[b]	215[b]	208
All-causes rate[c]	29.4	29.3	31.0	27.5	20.7	27.6	30.2	28.0
Fall-related rate[c]	*21.1*	*22.0*	*20.8*	*20.5*	*16.1*	*23.8*	*22.3*	*20.9*

[a]Source: CFOI=Census of Fatal Occupational Injuries, Bureau of Labor Statistics, Department of Labor.

[b]These employment values were not reported in the BLS publications referenced and were estimated by backcalculating from BLS-provided fatality rates.

[c]The fatality rate is the number of deaths per 100,000 workers.

(DAFW incidents). During 1992–2000, more than 17.6 million workers suffered serious injuries, an average of 1,960,000 per year. The yearly BLS Survey of Occupational Injuries and Illnesses is also known as the Annual Survey. Table 6 lists the number of DAFW cases for all U.S. private industry, for all types of fall events, and for falls to a lower level. The number of DAFW cases that occurred in 2000 (1,664,018) is about a 29% decrease from the 1992 value. Median number of DAFW per case has varied between 5 and 6 days during the nine years (Table 6).

From 1992 to 2000, 3,019,803 workers (17.1%) were seriously injured by falling at work. The median DAFW for all types of fall-related injuries varied between 7 and 8 days (Table 6). Inju-

Table 6. Frequency of Days-Away-From-Work (DAFW) Cases, with Median DAFW, in Private Industry, Caused by All Types of Falls and Falls to a Lower Level, 1992–2000[a]

	Total days-away-from-work (DAFW) cases					
	Private industry		All types of falls		All falls to lower level	
Year	Number DAFW cases	Median DAFW	Number DAFW cases	Median DAFW	Number (%)[b] DAFW cases	Median DAFW
1992	2,331,100	6	374,800	8	116,500 (31.1%)[b]	10
1993	2,252,591	6	370,112	7	111,266 (30.1%)[b]	10
1994	2,236,639	5	393,308	7	111,308 (28.3%)[b]	10
1995	2,040,929	5	343,929	7	104,801 (30.5%)[b]	10
1996	1,880,525	5	330,913	7	98,544 (29.8%)[b]	10
1997	1,833,380	5	313,335	8	99,882 (31.9%)[b]	12
1998	1,730,534	5	292,090	8	95,460 (32.7%)[b]	10
1999	1,702,470	6	297,499	7	93,881 (31.6%)[b]	10
2000	1,664,018	6	303,817	8	95,329 (31.4%)[b]	11
Total	17,672,186	—	3,019,803	(17.1% of total)	926,971 (30.7%)[b]	(5.2% of total)

[a]Source: Survey of Occupational Injuries and Illnesses (the Annual Survey), Bureau of Labor Statistics, U.S. Department of Labor.

[b]This (value) is a percentage of "all types of falls" (column 4) for that year.

J. Constr. Eng. Manage., 2004, 130(6): 895-907

Table 7. Proportion of Private Industry Days-Away-From-Work (DAFW) Cases, in Private Industry and Private Sector Construction, Caused by Falls and Fall-to-Lower-Level Events, 1992–2000[a]

		Private construction, DAFW cases					
Year	Private industry, total DAFW cases	Total (% of column 2)		Total fall related (% of column 3)		Total fall-to-lower-level (% of column 3)	
1992	2,331,100	209,564	(9.0)	41,500	(19.8)	24,932	(11.9)
1993	2,252,591	204,769	(9.1)	41,787	(20.4)	23,748	(11.6)
1994	2,236,639	218,835	(9.8)	45,850	(21.0)	24,726	(11.3)
1995	2,040,929	190,591	(9.3)	39,362	(20.6)	22,634	(11.9)
1996	1,880,525	182,334	(9.7)	38,200	(21.0)	21,382	(11.7)
1997	1,833,380	189,839	(10.4)	37,667	(19.8)	21,982	(11.6)
1998	1,730,534	178,341	(10.3)	36,699	(20.6)	21,081	(11.8)
1999	1,702,470	193,765	(11.4)	40,061	(20.7)	22,381	(11.6)
2000	1,664,018	194,410	(11.7)	41,140	(21.2)	24,374	(12.5)
Total	17,672,186	1,762,448	(10.0)	362,266	(20.6)	207,240	(11.8)

[a]Source: Survey of Occupational Injuries and Illnesses (the Annual Survey), Bureau of Labor Statistics (BLS), U.S. Department of Labor.

ries caused by falling to a lower level accounted for 30.7% of all types of falls. The median DAFW for fall-to-lower-level incidents has been as high as 11 and 12, but primarily has been 10 DAFW (Table 6).

Construction accounted for 10% of all DAFW injuries occurring in private industry in 1992–2000 (Table 7). All types of falls accounted for 20.6% of construction-related DAFW injuries, while fall-to-lower level injuries accounted for 11.8% of construction DAFW injuries for 1992–2000. Thus, for every seven fall-related serious injuries in construction, four involved a fall to a lower level.

Of the 207,240 fall-to-lower-level DAFW injuries that occurred in construction over the nine years, 48,920 (23.6%) occurred in General Building (SIC 15), and 140,888 (68.0%) in Special Trades (SIC 17) (Table 8). Of the 48,920 fall-to-lower-level injuries, 57.8% occurred in Residential Building (SIC 152) and 40.5% in Nonresidential Building (SIC 154). The number of DAFW injuries occurring in Residential work was higher in each of the nine years than the DAFW injuries in Nonresidential work (Table 8). As presented in Table 8 (SIC 152 versus SIC 154), these individual increases range from a low of 37 DAFW injuries (1.1%) in 1994 (3,316 versus 3,279) to a maximum increase of 1,767 DAFW injuries (104%) in 2000 (3,462 versus 1,695). Over the 9-year period, a yearly average of 938 (42.6%) more DAFW injuries occurred in Residential construction than in Nonresidential construction.

The Annual Survey lists nine subgroups for Special Trades. Five subgroups exceeded 10% of the SIC 17 9-year total (140,888), and are listed in Table 8. These five account for 78.0% of the total SIC 17 DAFW injuries. The next two trades are Carpentry and Floor work (SIC 175) and Painting and Paper hanging (SIC 172), averaging 8.6% and 7.4% of the SIC 17 9-year total.

Total injuries caused by fall-through events are separated into the five BLS work site categories—ROs and FOs, SLs, and RSs and FSs (Table 9). Three variables are presented: (1) Yearly listing of total injuries for each work site, (2) median DAFW (in brackets), as reported in the BLS Annual Survey, and (3) total calculated DAFW (in parentheses). Both variables (2) and (3) are needed to understand the overall scope of the serious injuries that occurred in the five work sites. Median DAFW (variable 2) is a measure of the severity of the resulting injury (impact on the individual worker). Total calculated DAFW (variable 3) is a measure of the overall effect of all injuries (overall impact on the construction industry).

Individual median DAFW values in Table 9 range from 3 to 72. Since fall-through events are a subset of falls-to-lower-level, individual median values (Table 9) should be compared to the median fall-to-lower-level DAFW values in Table 6 (i.e., 10, 11, and 12). This will provide an indication as to how severe these individual (values) are, and indicates where workers may be more likely to be seriously injured. When the individual median values from Table 9 are compared to those in Table 6, 29 of 45 (64.4%) individual median values exceed the corresponding yearly median values. As seen in Table 9, some *median* values for the time to return-to-work were as high as 50 to 70 work days (i.e., 10 to 14 work weeks), which means that many workers required even longer time periods to return to work than these already-excessive values.

For 1992–2000, 21,985 workers fell through the five work-site types (Table 9), and were injured seriously enough to miss a collective (conservative) total of 350,934 work days. Each work site lists the yearly value, which was obtained from the BLS Annual Surveys, for the median DAFW for fall-to-lower-level incidents. The average of these nine (median) values for RO, SL, and RS work sites was 36, 35, and 25 DAFW, respectively, compared to 10 DAFW for all private industry fall-to-lower-level incidents. The average of the nine median values for the FO was 11 DAFW and for the FS, it was 12 DAFW.

Discussion

Fatal Injuries

The current study indicates that between 1992 and 2000, the annual number of work-related fatalities in U.S. private industry averaged 5,566, fluctuating from a high of 5,959 in 1994 to a low of 5,344 in 2000, a 10% decrease. While the overall occupational deaths are decreasing, the number of fatal injuries caused by all types of falls in U.S. private industry has increased 28% (from 552 in 1992 to 704 in 2000). Similarly, fatalities caused by workers *falling to a lower level in all U.S. employment (private, public,*

J. Constr. Eng. Manage., 2004, 130(6): 895-907

Table 8. Proportion of Fall-to-Lower-Level Days-Away-From-Work (DAFW) Cases, in Selected Portions of Private Sector Construction, 1992–2000[a]

Year	Total fall-to-lower-level DAFW cases, private construction	General building (SIC 15) number (% of column 2)	Residential building (SIC 152)	Nonresidential building (SIC 154)	Special trades (SIC 17) number (% of column 2)	Plumbing, heating, & a.c. (SIC 171) (n)	(%)[b]	Electrical work (SIC 173) (n)	(%)[b]	Masonry, stonework, and plastering (SIC 174) (n)	(%)[b]	Roofing, siding, and sheet metal (SIC 176) (n)	(%)[b]	Miscellaneous special trade contractors (SIC 179) (n)	(%)[b]
1992	24,932	5,317 (21.3)	3,030	2,193	17,488 (70.1)	3,118	(17.8)	2,590	(14.8)	3,786	(21.6)	1,862	(10.6)	2,290	(13.1)
1993	23,748	6,071 (25.6)	3,664	2,306	15,425 (65.0)	2,871	(18.6)	2,345	(15.2)	2,956	(19.2)	2,346	(15.2)	1,716	(11.1)
1994	24,726	6,634 (26.8)	3,316	3,279	16,187 (65.5)	2,782	(17.2)	2,558	(15.8)	2,969	(18.3)	1,860	(11.5)	2,709	(16.7)
1995	22,634	5,061 (22.4)	2,884	2,116	15,734 (69.5)	3,542	(22.5)	2,624	(16.7)	2,593	(16.5)	2,020	(12.8)	1,559	(9.9)
1996	21,382	4,670 (21.8)	2,707	1,932	14,746 (69.0)	2,809	(19.0)	2,583	(17.5)	2,547	(17.3)	2,535	(17.2)	1,404	(9.5)
1997	21,982	4,984 (22.7)	2,615	2,182	15,085 (68.6)	2,541	(16.8)	2,886	(19.1)	2,755	(18.3)	1,786	(11.8)	1,784	(11.8)
1998	21,081	5,352 (25.4)	3,111	2,067	14,074 (66.8)	2,354	(16.7)	2,531	(18.0)	2,271	(16.1)	1,921	(13.6)	1,955	(13.9)
1999	22,381	5,549 (24.8)	3,479	2,048	15,031 (67.2)	2,509	(16.7)	2,169	(14.4)	3,737	(24.9)	1,635	(10.9)	1,730	(11.5)
2000	24,374	5,282 (21.7)	3,462	1,695	17,118 (70.2)	3,613	(21.1)	2,251	(13.1)	1,954	(11.4)	2,424	(14.2)	2,251	(13.1)
Total	207,240	48,920 (23.6)	28,268	19,818	140,888 (68.0)	26,139	(18.6)[b]	22,537	(16.0)[b]	25,568	(18.1)[b]	18,389	(13.0)[b]	17,398	(12.3)[b]

[a]Source: Survey of Occupational Injuries and Illnesses (the Annual Survey), Bureau of Labor Statistics (BLS), Department of Labor.

[b]This (%) value is the corresponding share of the total in the "Special Trades (SIC 17)" column.

and self-employed) has increased 30% (from 507 in 1992 to 659 in 2000). Data are available for just the last 7 years for fatal injuries to private industry workers resulting from a fall to a lower level. From 1994 to 2000, fall-to-lower-level fatalities in private industry increased 15%, from 551 to 636.

Table 3 indicates that fatal injuries in U.S. private construction from *all causes* increased 26% (from 919 in 1992 to 1,154 in 2000). However, fatalities caused by *all types of falls* in U.S. private construction increased even more, to 40% (from 267 in 1992 to 374 in 2000).

The current study also indicates that during the period 1994–2000, a total of 403 roofers died, of which 303 (75.2%) died by falling to a lower level (Table 5). During the years 1994–2000, the fall-related fatality rates in the roofer occupation ranged from 16.1 deaths per 100,000 roof workers in 1998 to 23.8 deaths per 100,000 roof workers in 1999. Across the 7 years, the fatality rate for roofers caused by falling averaged 20.9 deaths per 100,000 workers, which is $4\frac{1}{2}$ times the fatality rate for all construction workers caused by falling.

For this study, analysis of the CFOI database focused on workers falling through an opening in the roof or floor, through the roof or floor surface when it collapsed under the worker, or through an already-installed SL fixture. During 1992–2000, the number of fatal injuries resulting from fall-through events has averaged 67 per year. This total is composed of an average of 31 deaths from workers falling through a RO or FO (46.3%), 19 from falling through a RS or FS (28.4%), and 17 deaths from falling through a SL (25.4%). Assuming a roof construction season of 12 months, then, on average, a worker died about every 4 work days by falling through an opening, a surface, or a skylight during the years 1992 to 2000.

Work-related fatalities caused by falls through skylights and roof openings were identified in the late 1980's as important safety concerns that resulted in the release of a NIOSH Alert related to roof worker activities near these work areas (NIOSH 1989). Subsequently, an injury reduction matrix was developed that identified the need to develop design criteria for increased strength characteristics for SLs, along with the need to specify in the building construction contract language the use of proper guarding of ROs and SL fixtures (Bobick et al. 1994). In 2000, NIOSH published a summary of data for selected fall-related events in the U.S. during 1980 to 1995 (Braddee et al. 2000). This document includes descriptions of 90 fall-related fatal investigations, conducted by NIOSH/DSR between 1982 and 1997, and discusses fall-prevention recommendations. Of the 90 fatalities, 24 resulted from a fall-through event.

The analysis of OSHA data conducted by Culver and Connolly (1994) on construction fatalities for 1985–1993 observed that "unprotected or improperly protected roof openings warrant as much attention as fall protection from roof edges". The same concern still exists a decade later.

Another analysis of work-related fatal falls in construction for 1984–1986 (Suruda et al. 1995) identified an annual average of: (1) 14 deaths from falls through poorly marked or unguarded ROs (45.2%), (2) 9 deaths from falls through weak roof structures (29.0%), and (3) 8 deaths from falls through SLs (25.8%). The frequency count of fall-through incidents has more than doubled from the mid-1980's to the end of the 1990's (current study). Possible explanations for the doubling are: (1) Increases in construction activity, and (2) comparing two different fatality surveillance systems. Despite the doubling in the count, the percentage distribution for fall-through incidents are virtually identical over the 15 years (1985–2000), in spite of increased training require-

J. Constr. Eng. Manage., 2004, 130(6): 895-907

Table 9. Proportion of Fall-Through Days-Away-From-Work (DAFW) Cases in U.S. Industry, for Specific Work Sites, with Annual Median DAFW Values, and Calculated Total DAFW, 1992–2000[a]

Year	All fall-through DAFW cases frequency and (total calculated DAFW)[c]	Fall-through roof opening frequency (median DAFW)[b] and (total calculated DAFW)[c]	Fall-through floor opening frequency (median DAFW)[b] and (total calculated DAFW)[c]	Fall-through skylight frequency (median DAFW)[b] and (total calculated DAFW)[c]	Fall-through roof surface frequency (median DAFW)[b] and (total calculated DAFW)[c]	Fall-through floor surface frequency (median DAFW)[b] and (total calculated DAFW)[c]
1992	3,200	300 [62]	1,400 [11]	100 [50]	500 [15]	900 [7]
	(50,389)	(6156)	(21,262)	(2168)	(8533)	(12,270)
1993	2,873	284 [48]	1,216 [5]	215 [4]	378 [12]	780 [14]
	(42,883)	(6189)	(14,525)	(3377)	(6192)	(12,600)
1994	2,911	210 [10]	1,161 [10]	102 [70]	495 [10]	943 [11]
	(42,378)	(3383)	(14,863)	(2735)	(6407)	(14,990)
1995	2,819	246 [43]	846 [13]	190 [3]	531 [17]	1,006 [12]
	(42,763)	(5356)	(13,254)	(2515)	(8890)	(12,748)
1996	1,866	107 [32]	825 [10]	55 [36]	345 [32]	534 [3]
	(29,776)	(2357)	(11,900)	(1467)	(7792)	(6260)
1997	2,582	181 [60]	1,169 [30]	236 [37]	359 [28]	637 [24]
	(51,015)	(3665)	(22,823)	(6914)	(6975)	(10,638)
1998	2,069	202 [9]	705 [6]	50 [19]	576 [27]	536 [10]
	(32,304)	(2617)	(9075)	(821)	(11,719)	(8072)
1999	1,570	100 [10]	617 [7]	80 [35]	168 [62]	605 [19]
	(25,316)	(1701)	(7842)	(1861)	(3313)	(10,599)
2000	2,095	128 [38]	627 [10]	65 [72]	466 [25]	809 [6]
	(34,110)	(3458)	(9129)	(1224)	(8339)	(11,960)
Totals	21,985	1,758 [35][d]	8,566 [11][d]	1,093 [36][d]	3,818 [25][d]	6,750 [12][d]
	(350,934)	(34,882)	(124,673)	(23,082)	(68,160)	(100,137)

[a]Source: Survey of Occupational Injuries and Illnesses (the Annual Survey), Bureau of Labor Statistics, Department of Labor.

[b][Median DAFW]=Median number of days away from work for each incident. (From each year‘s Annual Survey, BLS, DoL.)

[c]The Annual Survey provides a breakdown of total days-away-from-work cases into the following categories—1 day, 2 days, 3–5 days, 6–10 days, 11–20 days, 21–30 days, and 31 days or more. These yearly breakdown values were used to estimate the total number of days missed from work because of the five fall-through incident types. See explanation in Methods section.

[d]The [value] is the average of the nine yearly median values listed in the above column.

ments for employers, and an increase in the availability of protective systems to guard openings and SLs. There is no easy answer to explain the lack of improvement in the percentage of deaths related to falls through openings or SLs. Existing fall-prevention systems should be evaluated under controlled conditions as part of normal work duties to enhance their acceptability. Also, future research should attempt to develop other types of passive engineering products that will assist in eliminating potential fall-through fatalities.

Serious Injuries

The annual number of work-related serious incidents in U.S. private industry has declined from 2.33 million in 1992 to 1.66 million in 2000 (28.6% reduction) (Table 6). Serious injuries caused by all types of falls in private industry have fluctuated across the 9 years, but had an overall decrease of 18.9% from 1992 to 2000. Serious injuries caused by falls to lower level in private industry have had a similar decrease (18.2%), from 116,500 in 1992 to 95,329 in 2000 (Table 6).

For 1992–2000, the annual number of serious incidents occurring in U.S. private construction (from all causes) averaged slightly less than 196,000. Across the 9 years, the number of serious incidents decreased slightly (7.2%) from 209,564 in 1992 to 194,410 in 2000 (Table 7). Serious injuries in construction caused by a fall-to-a-lower level decreased 15% from 1992 to 1998, followed by a 15% increase from 1998 to 2000 to virtually the same level as 1992 (2% decrease). Over the 9 years, 207,240 construction-related serious injuries were the result of a fall-to-lower-level incident. These represent about 12% of all DAFW incidents that occurred in construction.

An important subset of the fall-to-lower-level occurrences includes those involving a fall-through event. The 9-year total of 21,985 incidents (Table 9) accounted for a conservative estimate of 350,934 missed work days. Part of the conservative approach involved assigning only 31 missed days of work to the cases that had missed 31 or more workdays. In 14 of 45 yearly totals (Table 9), the median days away from work, which are listed in brackets [ ], actually exceeded 31. If the appropriate median value were used in these 14 instances, the total number of (calculated) days away from work would be even greater for the 21,985 fall-through occurrences for 1992–2000. For the 14 instances that the median days away from work exceeded 31 (listed in Table 9), six of them occurred for ROs, six for SLs, and two for RSs.

J. Constr. Eng. Manage., 2004, 130(6): 895-907

Estimated Costs of Fall-Related Injuries

An important point is that many of the serious injuries had recovery times that exceed the median values of 62 or 70 missed days. Thus, the overall scope of the required recovery times (12 to 14 work weeks *and more*) for the fall-through injuries in these three categories is extremely lengthy, and verifies the severity of the injuries that occur from falls through ROs, SLs, and RSs. Fall-prevention efforts should have renewed focus in these three categories.

The total cost associated with these serious injuries is comprised of two components—direct and indirect costs. Direct costs include medical payments for the injuries, workers' compensation costs for missed work time, equipment or parts replacement if breakage occurred, and other ancillary expenses such as ambulance service charges and medical supplies used at the job site. Indirect costs include items such as downtime while the incident is investigated, clean-up costs, administrative time for dealing with the injury, training of replacement workers (especially if a new hire is required), and a decrease in productivity (because of new hire inefficiency or from a reassigned permanent worker unfamiliar with new job duties). Laufer (1987) mentions that three items that contribute greatly to the overall costs are "diminished efficiency of the injured after recovery; crew time loss after the accident; and crew productivity loss due to replacement worker." LaBelle (2000) discusses a variety of factors that should be considered when determining total costs of incidents involving missed work days.

A conservative estimate, which has been chosen for this discussion, is that direct and indirect costs are equal, and that the amount paid in medical expenses and workers' compensation payments actually represents only half of the overall costs. Other estimates have been more robust and have suggested that the indirect costs range from two to three times the direct costs (Gice 2001) to three to five times the direct costs (Liberty Mutual 2001). A study conducted by the Construction Industry Institute (ENR 1990) indicated that when legal costs are included, indirect costs can escalate to 20 times the direct costs of medical and compensation. Recent information corroborates this estimate. A random sample of fall-through incidents that were litigated showed that the cost for four fatalities ranged from $550,000 to $1.4 million (settlement dates were 1985–1990), and for six nonfatal incidents, from $285,000 to $3.54 million (1985–1992) (L. Barbe, personal communication, 2002).

A Liberty Mutual press release (February 2001) dealt with the development of a *Workplace Safety Index*. The development of the *Safety Index* involved Liberty Mutual using its own claims information, along with data from BLS and the National Academy of Social Insurance, to determine the ten leading causes of injuries and illnesses for 1998. The total amount paid in wages and medical payments (direct costs) was $38.7 billion (Liberty Mutual 2001). Falls-to-lower level was the fourth most costly (following overexertion, falls on same level, and bodily reaction) and accounted for 9.33% of the total or $3.61 billion. Using data from Tables 6 and 9 for 1998, the 2,069 fall-through incidents amounted to 2.17% of the 95,460 fall-to-lower-level cases. Thus, the corresponding direct costs for the 1998 fall-through injuries amount to $78.337 million (2.17% of $3.61 billion). Thus, the direct costs for each of the 2,069 fall-through incidents amounted to $37,862. Using the conservative estimate that direct costs equal indirect costs, then the total (combined) cost for each of the 2,069 incidents is twice the $37,862, or an average of $75,724 per incident.

Other information related to the cost of injuries indicated that fractures averaged $23,138 per claim (Fefer 1992). Although not stated, the assumption was made that this cost was from 1991. To determine a 1998 equivalent value, an on-line inflation calculator (at www.bls.gov) was utilized to determine an updated cost. Thus, the direct costs for fractures, which is the likely result when a worker survives a fall through a RO or through an unguarded SL, was $27,691 in 1998. Using the same conservative estimate that indirect and direct costs are equal, the total (combined) cost would be $55,382. This provides a reliable range ($55,000 to $76,000) for the cost of a 1998 serious injury caused by a fall-through event.

When compared to the total number of roofs being installed in a year throughout the U.S., a fall-through incident happens rather infrequently, and might actually be considered a rare event. However, when an incident does occur, the excessive costs associated with these potential tragedies could be economically disastrous to small- or medium-sized construction companies. The potential for a fall-through incident to occur is present on every job site, and can be eliminated fairly easily.

Readers wishing to estimate injury costs on their own can access a recent on-line publication available from the European Agency for Safety and Health at Work (Occupational Safety & Health E-News 2002). The article, "Inventory of socio-economic costs of work accidents," is summarized in Fact Sheet 28. The article and the summary are both available at: http://agency.osha.eu.int/. It uses standard spreadsheet software to calculate the total costs of workplace incidents (including "hidden costs") and then permits a cost-benefit analysis to be conducted that compares the financial benefit of investing in preventive measures, and compares them with the costs of not having the same preventive measures.

Fall-Prevention Equipment

OSHA regulations for the construction industry [29 CFR Sec. 1926.501(b)(4)(i)] state that "*Each employee on walking or working surfaces shall be protected from falling through holes (including skylights) more than 6 feet* (*1.8 m*) *above lower levels, by personal fall-arrest systems, covers, or guardrail systems erected around such holes*." (Mancomm 2002), and that "*Each employee on a walking/working surface shall be protected from tripping in or stepping into or through holes (including skylights) by covers*." [29 CFR Sec. 1926.501(b)(4)(ii)] (Mancomm 2002). If used properly, personal fall-arrest systems can be quite effective. However, they serve as a fall-protection measure, not as a fall-prevention device. This section will focus primarily on products and materials that can be used to prevent the fall from occurring in the first place.

Openings/Holes

Smaller holes that may be a tripping hazard for a worker or may permit a hand tool or small objects to drop through it are not the focus here. Instead, this discussion considers holes (in floors or roofs) that are large enough that a worker can fall through if left unguarded or uncovered. These types of openings will eventually permit items, such as a stairway, elevator shaft, or heating, ventilating, and air conditioning ductwork, to pass through from floor to floor. As the structure progresses upward, each floor has a corresponding opening. All of the openings should be either covered or protected with a guardrail system along the perimeter.

Often, ordinary building materials, such as plywood, are used to cover an opening. To provide adequate protection, whatever

J. Constr. Eng. Manage., 2004, 130(6): 895-907

material is used has to have sufficient strength, has to be properly secured, and "marked with the word 'HOLE' or 'COVER' to provide warning of the hazard," as specified in OSHA regulation 29 CFR Sec. 1926.502(i)(4) (Mancomm 2002). If it is not secured and marked, it is like setting a deadly trap for the other workers in the crew (Barnhard 2001). Fatal injuries have occurred when a worker has stepped on an unsecured covering. When the unsecured cover shifted, the worker fell through the newly created opening to his death (McVittie 1995). Other injuries have occurred when a worker picked up the sheet of plywood covering the hole, with the intention of using it elsewhere, and then stepped directly into the opening. Both fatalities and serious injuries have occurred this way. Thus, it is critical that all hole coverings should be secured. However, if a secured cover has to be removed during the construction process, then a properly trained worker should be equipped with a correctly anchored personal fall-arrest system for protection from falling into the uncovered roof or floor opening.

Job-built guardrails can be constructed from 2 in. by 4 in. lumber and then left in place. If supplies have to be brought up through that opening or access is needed for any reason, the job-built guardrail will be removed and may or may not be replaced, as it should be. If the two-by-fours are damaged when they are removed, it is less likely that the guardrail will be rebuilt.

There are a variety of commercially available products that can be used to easily construct a guardrail around roof or floor openings, and can be removed and then reinstalled. One product, made of high-strength polymer, is a support base that is designed to be used on low-slope (flat) surfaces only. The configuration is such that a pair of two-by-fours can be inserted vertically so cross members can be attached at the top- and midrail locations. If toe boards are needed, the design permits a two-by-four to be easily inserted into the base for that purpose. A second product, made of extruded aluminum, is a bracket that has openings at the top- and midrail height so two-by-fours can be slid through them and easily attached in place. The base of the bracket is adjustable to permit its usage on a flat surface and on three different roof pitches. The advantage to both of these products is that they can be installed quickly, easily removed from around the opening, and then are able to be reused without having to use additional materials. These products save preparation time and reduce material costs.

Skylights

SLs have increased in popularity both for family residences, as well as for commercial and industrial buildings. SLs are used to illuminate homes, office buildings, shopping centers, and numerous buildings. Availability of inexpensive, easily installed, weather-proof plastics has contributed to this trend (Bobick et al. 1994). SLs that are designed to melt during a structural fire have replaced traditional louvered smoke vents as a way to remove smoke from a burning building (Bobick et al. 1994). Before the SL fixture is installed in the roof, an unguarded opening represents a potential for a serious or fatal injury, as discussed previously. However, even after the SL is installed, it can represent a potential fall-related injury or fatality to maintenance and service personnel who have to go on the roof to complete routine tasks. Unguarded SLs are potential fall hazards to workers because the SL material, referred to as the lens (Kirby 2002), may not be designed to support the weight of a worker when stepping, sitting, or falling on it.

SLs are made in both flat and domed configurations. Flat plastic sheets can be increased in thickness to increase the strength capabilities. However, the thickness of domed plastic cannot be easily increased because of the physical requirements when the plastic material has to be bent. Thus, the domed configuration has the potential for breaking underneath the dynamic loading of a worker sitting down or falling against the skylight lens. SL manufacturers should consider investigating the use of new technologies and high-strength materials that will not interfere with the light transmissibility.

Currently, some SL manufacturers have been including warning decals on the SL framework or on the plastic lens itself. Although well intentioned, warning labels are definitely inferior to other protective measures, such as SL screens. There are at least two manufacturers of protective screens that are designed to fit over both flat and domed skylights. These products can be effective in protecting workers if they are installed according to the manufacturer's instructions.

SLs are required to be protected by a screen or a fixed standard railing [29 CFR Sec. 1910.23(a)(4)]. Requirements of the protective screen are specified in 29 CFR Sec. 1910.23(e)(8), which states that "they are capable of withstanding a load of at least 200 pounds applied perpendicularly at any one area on the screen. … [and] under ordinary loads or impacts, they shall not deflect downward sufficiently to break the [skylight lens] below them." A protective safety screen costs approximately $125 and requires two workers about twenty minutes to install. Data from Tables 2 and 9 indicate that from 1992 to 2000, 150 of 605 fall-through fatalities (24.8%) involved SLs, and that 1,093 of 21,985 fall-through severe injuries (5.0%) involved SLs, with a median recovery time of 36 work days. Comparing these two percentages gives an indication that if a worker falls through an unguarded skylight, the likelihood is much greater that the fall will result in a fatality and not just a serious injury. Best safety practice dictates that SLs should always be guarded by a screen or a standard guardrail.

Surfaces

The third area of this study is falls through RSs and FSs. These are obviously more difficult to identify and eliminate than the other two areas. These surfaces can be considered "zones of weakness" that are not easy to identify. Preventing workers from stepping onto unrecognized weak areas is not easily accomplished. In some instances, the underside of the roof or floor surface might be accessed and visually inspected by using a powered lift to raise the worker to the roof. This type of equipment has to be used carefully since it can be a potential fall hazard also. Possible technologies that may be used to scan walking/working surfaces might include the use of ultrasonic or infrared instrumentation. However, identifying and developing protective and preventive measures for weakened walking or working surfaces should be the subject of future research investigations.

Role of Safety Attitudes

Ringen et al. (1995) point out that the construction work environment and the organization of the required tasks are both "complex and constantly changing." High turn over in the workforce and a lack of supervisory continuity contribute to a lack of consistency among a crew of workers. Lack of supervisory continuity can occur when an employee works for different employers in a construction season because specialized tasks, like roofing, can be quickly completed. Thus, diverse individuals are often required to work together to complete short-term jobs on short notice. Generally, workers are able to quickly get focused to function as an

J. Constr. Eng. Manage., 2004, 130(6): 895-907

efficient team when a specific construction task has to be completed. Many times, however, this same teamwork does not exist when safety concerns need to be addressed. The team may not complete their tasks with safety as a priority. Ringen et al. (1995) state that "it is difficult to develop effective, safe teamwork under [constantly changing] conditions." Similar to professional sports teams, professional work teams have to be aware of and warn other crew members about unsafe conditions, and encourage safe behavior in one another.

Weeks and McVittie (1995) reviewed a 1994 study that dealt with the attitudes and safety practices of road maintenance workers and their immediate supervisors. The 1995 review stated that "workers felt that the supervisor's management methods had the greatest effect on safe work habits." Weeks and McVittie state that a common theme in studies they reviewed was that "positive attitudes toward safety by workers and management are mutually supportive, and their attitudes tend to rise and fall together." Therefore, management should fully support developing and enforcing a proactive fall-prevention program so workers will routinely follow safe work behaviors. Workers supervised by safety-conscious managers will consider safety to be important and follow safe practices while working.

Relevance to Both Researchers and Industry Practitioners

This analysis has compiled construction-related injury and fatality data from published BLS documents. Although the "fall-through" event occurred infrequently, when it did happen, the median length of time off work was $2\frac{1}{2}$ to $3\frac{1}{2}$ times as long as other fall-from elevation injuries that occurred in construction (25 to 35 days off work versus 10 days). Analyses of incidents that focus on identifying the underlying contributory causes need to be conducted by safety researchers.

Additionally, employers and industry practitioners should alert first-line supervisors, work crews, and competent persons about these dangerous work locations on all types of residential or commercial building construction. Keeping workers aware and properly trained will help to keep them alert to the dangers associated with fall-through types of incidents. These particular hazards are often obvious and easily rectified with easy-to-install fall-prevention commercial products.

Summary

Fatal injuries involving workers falling through ROs and FOs and RSs, and FSs, and through unguarded SL fixtures have consistently claimed 55 to 75 workers each year since the mid-1980's. The current study indicates that a fatality occurs, on average, about every 4 work days from a fall-through event during a 12-month roof construction season. The roofer occupation has an average fall-related fatality rate (20.9) that is $4\frac{1}{2}$ times greater than the average fall-related fatality rate of 4.6 deaths per 100,000 workers for all construction activities.

Workers who survive the fall-through events may be severely injured. On average, 2,443 workers were seriously injured each year during the period 1992–2000 from a fall-through incident. The resulting median number of work days missed related to injuries from falling through roof openings ranged (across the nine years) from 9 to 62 work days, and from 3 to 72 work days for falls through skylights. The current study presents data that suggest that the total costs (direct and indirect costs combined) associated with a serious fall-through injury that occurred in 1998 ranged from $55,000 to $76,000 per incident.

U.S. employers are required to protect their workers from falling by instituting a comprehensive fall-protection program. Details of such a program are specified in the OSHA regulations, Parts 1910 and 1926. However, some key requirements include developing a site-specific fall protection plan; securely covering holes and openings; installing a guardrail, safety net, or SL protection system; providing workers with personal fall-arrest equipment; as well as, providing work-site supervisors and employees with appropriate fall-related safety training. Developing and using such a comprehensive fall-protection plan can prevent worker fatalities, severe injuries, and related costs associated with fall-through incidents.

Acknowledgments

The writer would like to extend his appreciation to Mr. David Fosbroke, Statistician, Division of Safety Research (DSR), NIOSH whose assistance at the beginning of this effort was helpful in providing focus, and throughout for his regular detailed review comments and insightful suggestions; to Mr. Dan Long, formerly with NIOSH/DSR and currently with the Minnesota Department of Health, for assistance with fatality rates and his review of the document; to Ms. Doloris Higgins, Occupational Safety and Health Specialist, DSR, NIOSH for her thorough and knowledgeable review; and, to Ms. Peggy Suarez, Senior Economist, Bureau of Labor Statistics, for completing a review on such short notice. Thanks also goes to Mr. Lewis Barbe, National Chairman of the American National Standards Institute A10.24 Committee on Roofing, for his review comments, his help in supplying background documents, and his personal communication input.

References

Barnhard, J. (2001). "Roof holes are death traps." *The Journeyman Roofer & Waterproofer*, 61(4), 10–11.

Bobick, T. G., Stanevich, R. L., Pizatella, T. J., Keane, P. R., and Smith, D. L. (1994). "Preventing falls through skylights and roof openings." *Professional Safety*, 39(9), 33–37.

Braddee, R. W., Hause, M. G., and Pratt, S. G. (2000). "Worker deaths by falls: A summary of surveillance findings and investigative case reports." *Publication No. 2000-116*, U.S. Department of Health and Human Services (NIOSH), Cincinnati.

Bureau of Labor Statistics. (1994). "Fatal workplace injuries in 1992: A collection of data and analysis." *Rep. No. 870*, U.S. Dept. of Labor, Washington, D.C.

Bureau of Labor Statistics. (1995a). "Occupational injuries and illnesses: Counts, rates, and characteristics, 1992." *Bull. No. 2455*, U.S. Dept. of Labor, Washington, D.C.

Bureau of Labor Statistics. (1995b). "Fatal workplace injuries in 1993: A collection of data and analysis." *Rep. No. 891*, U.S. Dept. of Labor, Washington, D.C.

Bureau of Labor Statistics. (1996a). "Fatal workplace injuries in 1994: A collection of data and analysis." *Rep. No. 908*, U.S. Dept. of Labor, Washington, D.C.

Bureau of Labor Statistics. (1996b). "Occupational injuries and illnesses: Counts, rates, and characteristics, 1993." *Bull. No. 2478*, U.S. Dept. of Labor, Washington, D.C.

Bureau of Labor Statistics. (1997a). "Fatal workplace injuries in 1995: A collection of data and analysis." *Rep. No. 913*, U.S. Dept. of Labor, Washington, D.C.

J. Constr. Eng. Manage., 2004, 130(6): 895-907

Bureau of Labor Statistics. (1997b). “Occupational injuries and illnesses: Counts, rates, and characteristics, 1994.” *Bull. No. 2485*, U.S. Dept. of Labor, Washington, D.C.

Bureau of Labor Statistics. (1998a). “Occupational injuries and illnesses: Counts, rates, and characteristics, 1995.” *Bull. No. 2493*, U.S. Dept. of Labor, Washington, D.C.

Bureau of Labor Statistics. (1998b). “Fatal workplace injuries in 1996: A collection of data and analysis.” *Rep. No. 922*, U.S. Dept. of Labor, Washington, D.C.

Bureau of Labor Statistics. (1999a). “Occupational injuries and illnesses: Counts, rates, and characteristics, 1996.” *Bull. No. 2512*, U.S. Dept. of Labor, Washington, D.C.

Bureau of Labor Statistics. (1999b). “Fatal workplace injuries in 1997: A collection of data and analysis.” *Rep. No. 934*, U.S. Dept. of Labor, Washington, D.C.

Bureau of Labor Statistics. (1999c). “Occupational injuries and illnesses: Counts, rates, and characteristics, 1997.” *Bull. No. 2518*, U.S. Dept. of Labor, Washington, D.C.

Bureau of Labor Statistics. (2001a). “Occupational injuries and illnesses: Counts, rates, and characteristics, 1998.” *Bull. No. 2538*, U.S. Dept. of Labor, Washington, D.C.

Bureau of Labor Statistics. (2001b). “Fatal workplace injuries in 1998 and 1999: A collection of data and analysis.” *Rep. No. 954*, U.S. Dept. of Labor, Washington, D.C.

Bureau of Labor Statistics. (2002a). “Health and safety; injuries and illnesses; case and demographic characteristics; resource tables—1999.” ⟨http://www.bls.gov⟩ (Jan. 15, 2002).

Bureau of Labor Statistics. (2002b). “Health and safety; fatalities; annual data for census of fatal occupational injuries—2000.” ⟨http://www.bls.gov⟩ (Feb. 1, 2002).

Bureau of Labor Statistics. (2002c). “Health and safety; injuries and illnesses; case and demographic characteristics; resource tables—2000.” ⟨http://www.bls.gov⟩ (Jan. 22, 2002).

Culver, C., and Connolly, C. (1994). “Prevent fatal falls in construction.” *Safety + Health*, 150(3), 72–75.

Engineering News Record (ENR). (1990). “Cost of accidents is hidden.” *ENR*, 225(24), 20–21.

Fefer, M. D. (1992). “What to do about workers’ comp.” *Fortune*, 125(13), 80–82.

Gice, J. (2001). “The cost of comp.” *Occup. Health Saf.*, 70(2), 59–60.

Health and Safety Executive (HSE). (1998). “Health and safety in roof work.” *HSG 33. Her Majesty’s Stationery Office*, St. Clement’s House, Norwich.

Kines, P. (2001). “Occupational injury risk assessment using injury severity odds ratios: Male falls from heights in the Danish construction industry, 1993–1999.” *Hum. Ecol. Risk Asses.*, 7(7), 1929–1943.

Kirby, J. R. (2002). “Shedding some light on skylights.” *Professional Roofing*, 32(8), 26–29.

Kisner, S. M., and Fosbroke, D. E. (1994). “Injury hazards in the construction industry.” *J. Occup. Med.*, 36(2), 137–143.

LaBelle, J. E. (2000). “What do accidents truly cost?” *Professional Safety*, 45(1), 38–42.

Laufer, A. (1987). “Construction accident cost and management safety motivation.” *J. Occupational Accidents*, 8, 295–315.

Liberty Mutual. (2001). “Liberty Mutual reveals first-ever ranking of the leading causes of workplace injuries.” *Feb 26, 2001 Press Release* ⟨http://www.libertymutual.com/about/pressclub/press_workplace.html⟩ (Jan. 31, 2002).

Mancomm (Mangan Communication, Inc.. (2002). “Subpart M.” *29 CFR 1926*, OSHA Construction Industry Regulations, Davenport, Iowa, 302. ⟨http://www.mancomm.com⟩.

McVittie, D. J. (1995). “Fatalities and serious injuries.” *Occupational medicine: State of the art reviews* 10(2), Hanley and Belfus, Philadelphia, 285–293.

Occupational Health & Safety E-News of 09-23-02. (2002). “Tool allows cost-benefit analysis of preventive measures.” Available at ⟨stevenspub@processrequest.com⟩

Office of Management and Budget (Executive Office of the President. (1987). *Standard industrial classification manual*, U.S. Government Printing Office, Washington D.C. (Available from National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22161, Order No. PB 87-100012).

Parsons, T. J., and Pizatella, T. J. (1984). “Safety analysis of high risk activities within the roofing industry.” *Rep. No. PB 85-163236*, U.S. Department of Commerce, National Technical Information Service, Springfield, Va.

Parsons, T. J., Pizatella, T. J., and Collins, J. W. (1986). “Safety analysis of high risk injury categories within the roofing industry.” *Professional Safety*, 31(6), 13–17.

Personick, M. (1990). “Profiles in safety and health: Roofing and sheet metal work.” *Monthly Labor Rev.*, 113(9), 27–32.

Ringen, K., Englund, A., Welch, L., Weeks, J. L., and Seegal, J. L. (1995). “Why construction is different.” *Occupational Medicine: State of the Art Reviews* 10(2), Hanley and Belfus, Philadelphia, 255–259.

Suruda, A., Fosbroke, D., and Braddee, R. (1995). “Fatal work-related falls from roofs.” *J. Safety Res.*, 26(1), 1–8.

U.S. National Institute for Occupational Safety and Health (NIOSH). (1989). “Alert—Request for assistance in preventing worker deaths and injuries from falls through skylights and roof openings.” *NIOSH Publication No. 90-100*, Department of Health and Human Services, Cincinnati.

Weeks, J. L., and McVittie, D. J. (1995). “Controlling injury hazards in construction.” *Occupational Medicine: State of the Art Reviews* 10(2), Hanley and Belfus, Philadelphia, 395–405.

J. Constr. Eng. Manage., 2004, 130(6): 895-907