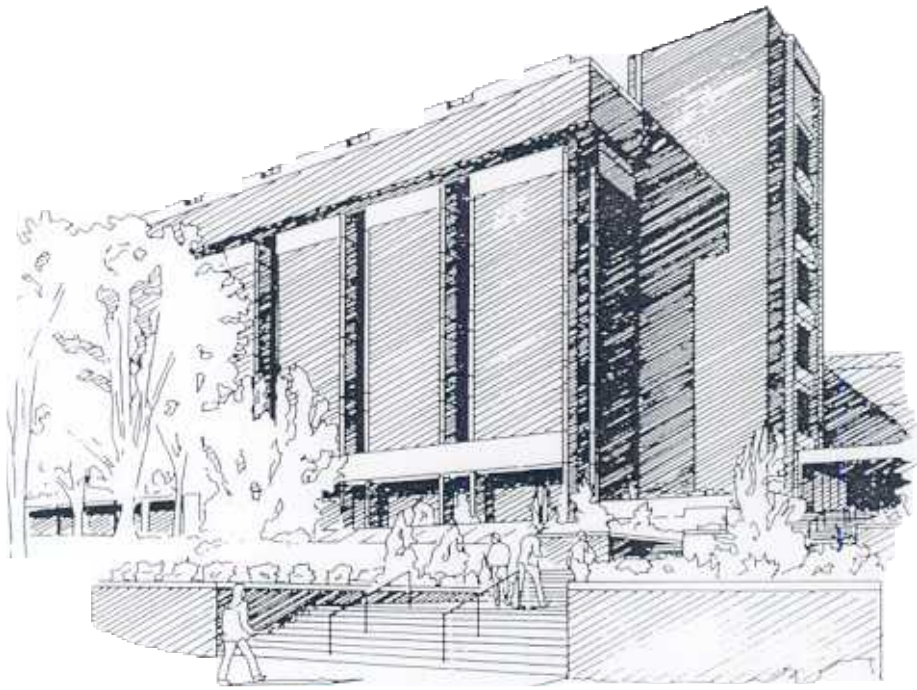

UNIVERSITY OF CINCINNATI
COLLEGE OF ENGINEERING

AN ERGONOMIC EVALUATION OF STEEL AND COMPOSITE MANHOLE (ACCESS) COVERS

Final Report

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ABSTRACT

This study was undertaken to determine which of the two manhole covers (also known as access covers), the conventional steel manhole cover or the newly designed composite manhole cover, was ergonomically superior and resulted in lower physical stresses during manual handling (removal and replacement). The acceptability of these stresses was also determined. Utilizing three different design criteria - psychophysical, biomechanical, and physiological - the two manhole covers were evaluated. Furthermore, removal of the composite manhole cover with the aid of a handle was also evaluated. Ten male and ten female teams, each comprising of two members, participated in the experimental evaluation. Their individual and team isometric back strengths and psychophysical lifting capacities for single and 5 consecutive exertions were determined. Also determined were their ratings of perceived exertion (RPE), spinal compressive force and heart rate at the maximum acceptable weight of lift (MAWL). The results indicated that:

the conventional steel manhole cover, which weighs 80.35 kg (177 lbs) and is 91.44 cm in diameter, is too heavy to be lifted safely by either one person or a team of two males or females. The weight of the steel manhole cover not only exceeded the average individual psychophysical lifting capacity of males and females (33.83 kg and 29.56 kg, respectively), it exceeded the average psychophysical lifting capacity of male and female teams as well (76.04 kg and 67.08 kg, respectively).

The spinal compression generated while lifting the steel manhole cover was 13210 N for individual lifting and 6190 N for team lifting. When these values are compared with the spinal column compressive strength (mean and standard deviation of 5700 $\pm$ 2600 N for males and 3900 $\pm$ 1500 N for females), it becomes clear that manual lifting of steel manhole cover is extremely hazardous and has the potential for inflicting very serious injuries.

Even though the steel manhole cover was never actually lifted by the subjects, lifting of relatively much lighter weights (psychophysical capacity) was perceived to be "somewhat hard" (average RPE value of 13.05 for males and 13.20 for females for individual lifting and average RPE value of 12.4 for males lifting in teams of two and 12.6 for females lifting in teams of two). This indicates that if the steel manhole cover was actually lifted, either by

a team or alone, the perceived exertion would have been, most likely, in the unacceptable region (well above 13).

Lifting the composite manhole cover (weighing 38.13 kg = 84 lbs) and 91.44 cm in diameter) conventionally (straight up) with handles was relatively less stressful than lifting MAWL but was still too hazardous for individuals to lift it alone as it still exceeded the psychophysical lifting capacity of individuals. In fact, only 4 out of 20 males were able to lift it; none of the females could lift it. The average spinal compression for males for individual lifting was 5849 N. Since the team psychophysical lifting capacity of both males and females exceeded the weight of the composite manhole cover (average spinal compression for team lifting the composite manhole cover = 2501 N), it would be safer to lift the composite manhole cover by a team instead of lifting it alone if the conventional lifting method (lifting straight up manually) is to be used. Thus, lifting the composite manhole cover is safer and team lifting it is a viable solution (conventional method), whereas lifting the steel manhole cover manually is completely unsafe. Lifting the composite manhole cover in a team would also provide a factor of safety of at least 36% for females and 56% for males.

The innovative method of removing the composite manhole cover using a handle resulted in somewhat greater physical stress than lifting it conventionally by a team. The magnitude of vertical force exerted while removing the composite manhole cover was determined to be 21.33 kg (47 lbs). The spinal compression at this load was estimated to be 2898 N. This provides a factor of safety of at least 50% for males and 26% for females, on the average. Removing the composite manhole cover with the aid of the handle was also perceived to be "light" (average RPE value of 10.25 for males and 10.00 for females).

While the average isometric back strength of males (55.38 kg) and females (45.80 kg) exceeded the weight of the composite manhole cover, it was far below the weight of the steel manhole cover. The team isometric back strength (149.07 kg for males and 120.15 kg for females) did exceed the weight of the steel manhole cover. This, however, does not

change the conclusion that lifting the steel manhole cover in teams of two is still unsafe, since the dynamic lifting capacity of teams are lower than the weight of the steel manhole cover. Lifting the steel manhole cover in teams of two would result in spinal compression force that would exceed the spinal column strength of almost all females and 63% of all males.

The composite manhole cover can be lifted safely by either a team of two, males or females, conventionally or by a single individual, male or female, with the help of the handle. The factor of safety is at least 26% for females and 50% for males.

The composite manhole cover is a far superior design compared to the steel manhole cover. The specific advantages of the composite manhole cover, over the steel manhole cover, are:

(1) lower and acceptable spinal compression for conventional lifting in a team of two or individual lifting using the handle.

(2) lower and acceptable perceived exertion either for conventional team lifting or individual lifting using the handle.

(3) ability to remove the composite manhole cover alone, with the help of the handle.

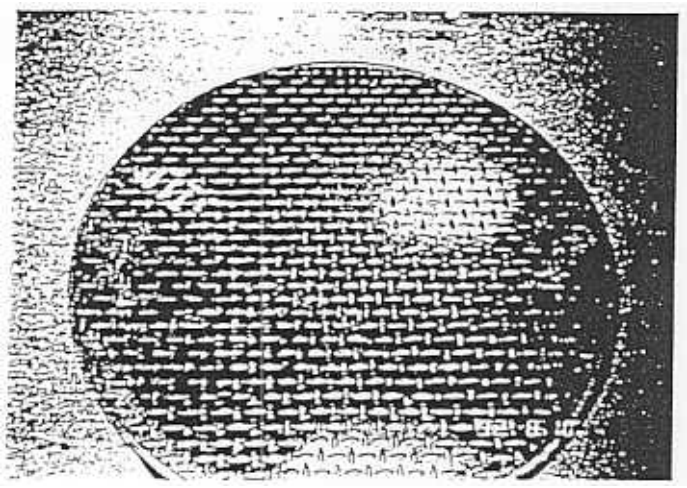
(4) the task can be performed by both males and females, working alone (lifting with the handle) or in a team (conventional lifting).

INTRODUCTION

Openings to underground passages, confined spaces, and underground submerged storage tanks are generally covered by steel manhole (access) covers. These steel manhole covers are removed and replaced manually to allow routine maintenance and service activities to be carried out. Manual removal and replacement of steel manhole covers, which can vary in diameter anywhere from 0.91 m (36 inch) to 1.067 m (42 inch) and weigh upwards of 80 kg (176 lbs), involves lifting the manhole cover clear and away from its seat (Figure 1).

The weight of the steel manhole cover, which far exceeds the recommended weight limit of the working population (Mital et al., 1992), makes manual lifting of steel manhole covers extremely hazardous. This is particularly true if the task is to be performed by an individual alone and without any mechanical aid. The situations in field frequently do not allow mechanical aids to be used and the assistance of a second person may not always be available. Under these circumstances, the individual is forced to carry out the task himself or herself. There are also occasions when several manhole covers, in a cluster, must be removed and replaced at one time. The added frequency of handling further increases the potential for serious injuries.

This study was carried out at the Ergonomics and Engineering Controls Research Laboratory of the University of Cincinnati with the express purpose of quantifying the physical stresses resulting from lifting the steel manhole cover and evaluating the benefits of an improved manhole cover design (composite manhole cover - Figure 2) and a unique method of removing and replacing these improved manhole covers (Figure 3).



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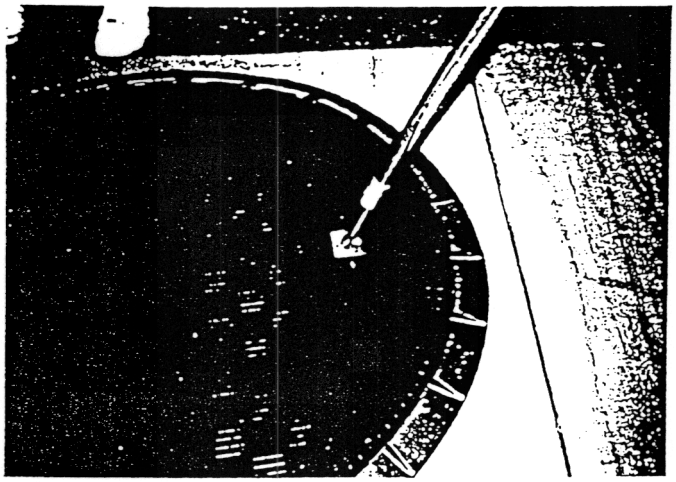

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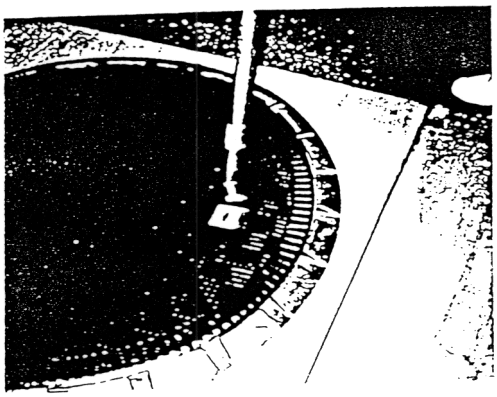

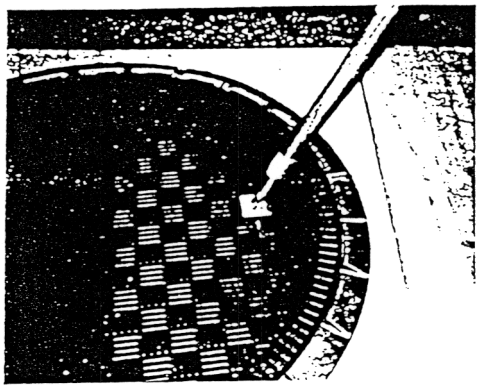

igure Sequence showing removal composite manhole cover with handle.

Specifically, the objectives of this laboratory study were:

1) To determine the population's capacity for lifting objects which have the same diameter and shape as the steel and composite manhole covers.

(2) To determine the lifting capacities of unmatched two-people teams (M-M and F-F)

(3) To determine how the weights of steel and composite manhole covers compare with individual and team lifting capacities.

(4) To determine if the unmatched two-person team is a viable solution for removing and replacing manhole covers.

(5) To determine physical stresses in the following cases:

   (a) lifting the steel cover - alone and in team (team members unmatched).

   (b) lifting the composite cover - alone and in team (team members unmatched).

   (c) lifting individual and team MAWL (team members unmatched).

(6) To determine how the conventional lifting by individuals compares with the suggested technique (cover removal with a handle) as far as the perceived exertion and physical stresses are concerned.

(7) To determine what specific advantages the composite manhole cover and the recommended cover removal and replacement technique provide.

METHODS

An experiment was designed and conducted in order to meet the objectives outlined above. The experiment involved participation of male and female volunteers, individually and in teams of two (males or females), and determination of:

(1) the isometric back strengths of individuals and unmatched teams (M-M; F-F).

(2) individual and unmatched team psychophysical capacities (M-M; F-F).

(3) ratings of perceived exertion (RPE) and physiological cost during the removal of manhole covers in case the psychophysical lifting capacities exceeded the weights of the manhole covers.

(4) spinal compressive forces imposed upon individuals and team members while lifting the manhole covers.

(5) RPE values when lifting the composite manhole cover and when removing it with a handle.

(6) RPE values and physiological costs when manhole covers and MAWL were lifted five times, successively.

Subjects

Twenty males and 20 females voluntarily participated in the study. The forty subjects formed 20 2-member teams (10 male teams and 10 female teams). All participants were required to complete a personal data form (Appendix A) and a consent form (Appendix B). Only healthy subjects were allowed to participate in the experiment. Those on medication and with a history of musculoskeletal disorder were screened. During the experiment, subjects were asked to wear work shoes and comfortable clothing.

Once the suitability of the individuals to participate in the experiment was established, a number of body size measurements were made on each individual for the purpose of establishing the sample population profile. Figure 4, for example shows the measurement of knuckle height. In addition to body size measurements, individual isometric back strength and team isometric back strengths were also measured. A special handle was built for measuring team isometric back strength (Figure 5).

Tables 1 and 2 show the distribution of the measurements made for males and females, respectively. The body size and individual isometric back strength values are comparable to those of the civilian population (Mital, 1984).

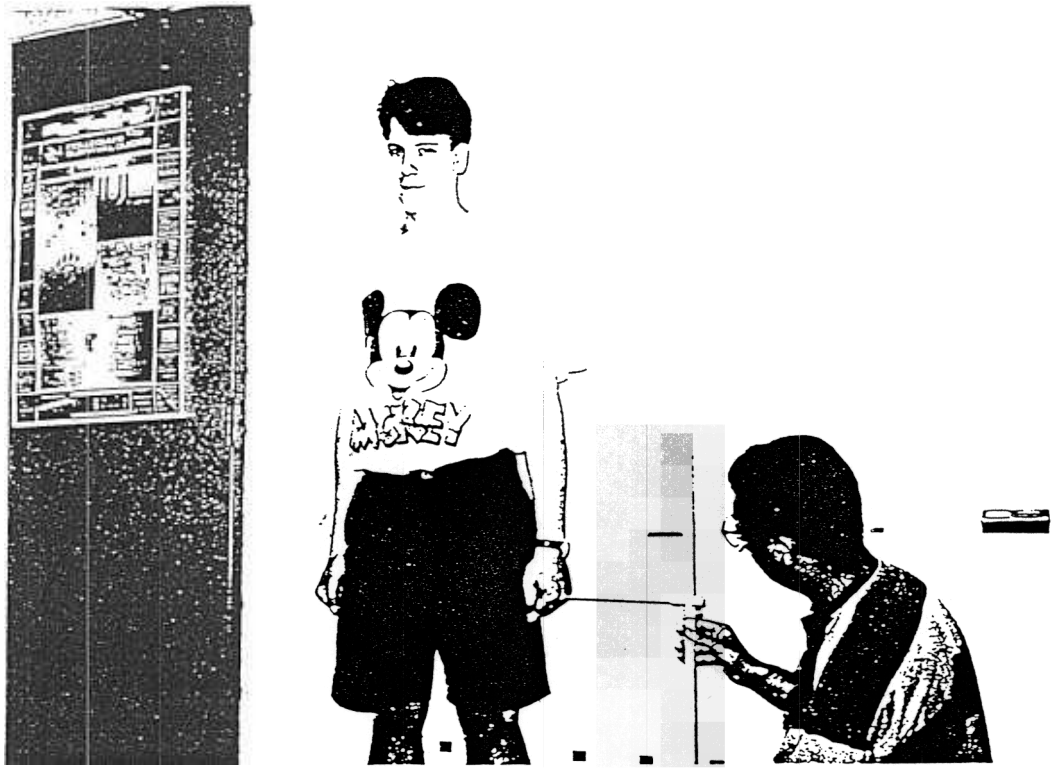

Figure 4. Measurement of knuckle height.

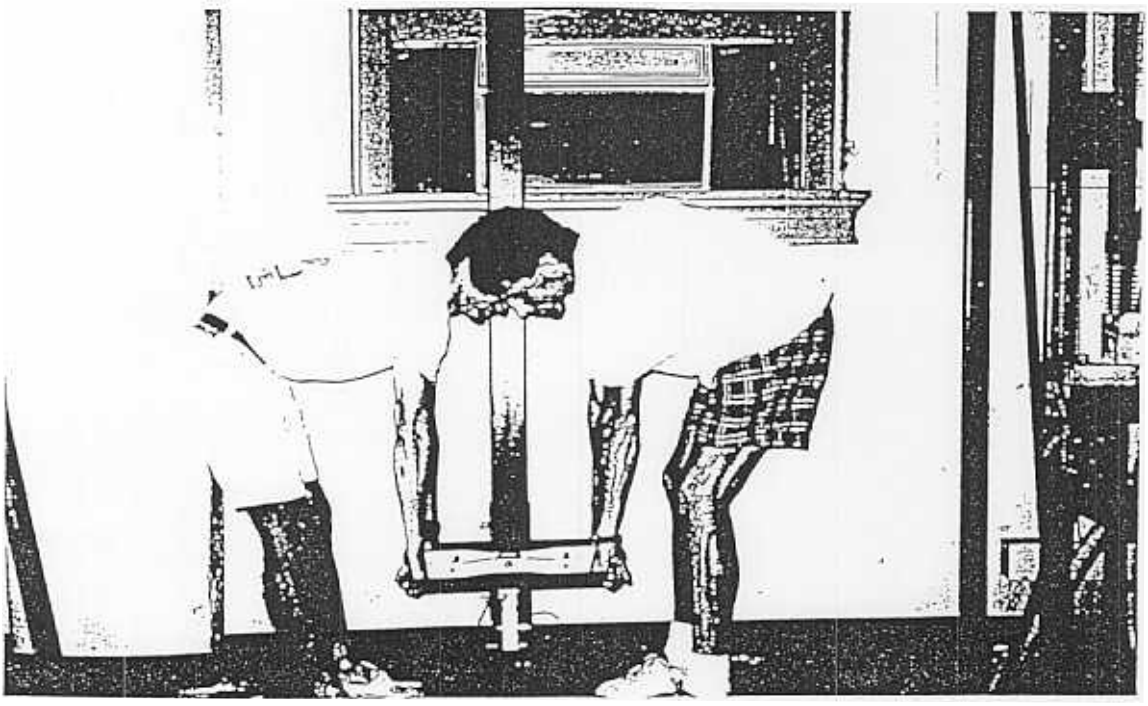

Figure 5. Measurement of team isometric back strength

Table 1 Distribution of measurements made on male subjects (N=20).

Attribute	Mean	Std. Deviation	Range
Age (years)	23.45	3.44	20-32
Stature (cm)	177.51	4.48	165.40-183.60
Body weight (kg)	70.65	7.20	57.20-87.62
Elbow height (cm)	110.85	6.95	93.60-121.10
Knuckle height (cm)	78.24	2.63	74.30-84.50
Forearm grip dist. (cm)	35.98	1.98	31.70-40.10
Chest width (cm)	29.69	1.99	26.20-34.40
Chest depth (cm)	18.94	1.33	16.30-21.30
Abdominal depth (cm)	17.82	1.85	14.20-22.50
Standing resting			
heart rate (bpm)	81.45	11.25	98-68
Max. heart rate (bpm)*	197.18	2.35	191.28-199.80
Isometric back strength (kg)			
Individual	55.38	15.04	37.07-85.96
Team	149.07	36.65	95.79-210.04

Maximum heart rate = 214 - 0.71 * Age in years.

Table 2. Distribution of measurements made on female subjects (N=20).

Attribute	Mean	Std. Deviation	Range
Age (years)	24.70	5.15	18.00-38.00
Stature (cm)	164.82	4.98	154.60-172.30
Body weight (kg)	58.90	6.70	49.94-72.18
Elbow height (cm)	106.63	7.62	98.30-133.30
Knuckle height (cm)	74.42	3.68	66.70-82.80
Forearm grip dist. (cm)	32.03	2.07	29.40-36.60
Chest width (cm)	26.79	1.13	24.80-28.60
Chest depth (cm)	17.90	1.66	14.70-21.00
Abdominal depth (cm)	15.72	1.62	13.10-18.90
Standing resting			
heart rate (bpm)	79.65	11.32	98.00-53.00
Max. heart rate (bpm)*	195.88	4.10	186.00-198.00
Isometric back strength (kg)			
Individual	36.22	10.37	19.52-65.22
Team	91.22	17.95	50.02-113.50

* Maximum hear rate = 214 - 0.71 * Age in years.

Experimental procedure

The experimental procedure involved determination of the following:

(1) Individual psychophysical lifting capacity (MAWL).

(2) RPE at the MAWL.

(3) team psychophysical lifting capacity (MAWL).

(4) Team RPE at the MAWL.

(5) RPE at the end of 5 consecutive lifts of individual and team MAWL (self-paced).

(6) Heart rates at the end of 5 consecutive lifts of individual and team MAWL (self-paced).

(7) Proportion of team MAWL lifted by each member.

(8) Individual and team RPE for single lift of 38.13 kg (weight of the composite manhole cover) weight in the event individual and/or team MAWL exceeded 38.13 kg.

(9) Individual and team RPE for 5 consecutive lifts (self-paced) of 38.13 kg weight in the manhole cover size container in the event individual and/or team MAWL exceeded 38.13 kg.

(10) Individual and team heart rates for 5 consecutive lifts (self-paced) of 38.13 kg weight in the manhole cover size container in the event individual and/or team MAWL exceeded 38.13 kg.

(11) RPE for removing the composite manhole cover with the handle once.

(12) RPE and heart rate for removing the composite manhole cover with the handle 5 consecutive times.

(13) The vertical force exerted in removing the composite manhole cover with a handle.

From these measurements, the following were calculated:

(1) Proportion of the team MAWL lifted by each member of the team.

(2) Spinal compressive forces during individual and team lifting.

(3) Spinal compressive forces when removing the composite manhole cover with the handle, lifting the composite manhole cover either individually or in a team, and lifting the steel

manhole cover either individually or in a team.

The modified psychophysical approach (Ayoub and Mital, 1989) was used to determine the maximum weights of lift acceptable to individuals and teams. Members of the team were not matched in any way - by height or body weight or isometric back strength, etc. The subjects, or teams, were randomly started with either a very heavy or very light load in a specially built fiberglass container. The diameter and shape of the fiberglass container was the same that of steel and composite manhole covers. The fiberglass container was fitted with two fixed handles. The distance between the handles was the same as for the steel manhole cover. Subjects were allowed to adjust the weight in the container (remove some weight from the weight already in the container or add some more weight to it) in order to arrive at the maximum acceptable weight of lift (MAWL - psychophysical lifting capacity). Figure 6 shows the fiberglass container, the location of the handles, and a male team attempting to determine its MAWL.

Once the MAWL was reached, the Borg scale was used to record the rating of perceived exertion (Borg, 1985). The heart rates at the MAWL were measured with the help of two Polar Heart Rate Monitors (oxygen consumption was also recorded initially but due to the very short duration of lifting, few seconds for a single lift to about 45 seconds for 5 consecutive lifts, it never stabilized and the readings, therefore, were of little use).

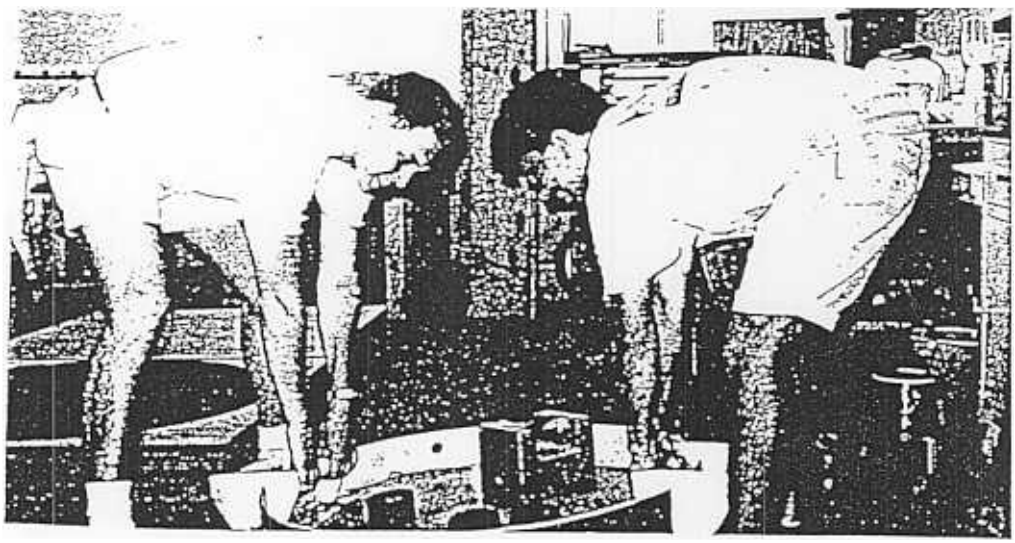

Figure 6. Determination of team MAWL.

If the individual or team lifting capacity exceeded 38.13 kg, the weight of the composite manhole cover, subjects and teams were asked to lift 38.13 kg in the fiberglass container. RPE values and heart rates for both single lift and 5 consecutive lifts were recorded.

Even though in some cases the team MAWL exceeded 80.35 kg (177 lbs), the weight of the steel manhole cover, this step was not repeated for the 80.35 kg weight since the weight was considered very unsafe for either individual or team lifting (Mital et al., 1992). The spinal compressive forces for the various loads lifted were determined from the 3-D dynamic biomechanical model developed by Kromodihardjo and Mital (1986, 1987). The factors of safety were estimated from the spinal column strength data provided by Jager and Luttmann (1991). The proportion of MAWL lifted by each member of the team was determined by adjusting the team MAWL in proportion to team members' height; the shorter member lifting more than the taller member. The vertical force necessary to remove the composite manhole cover from its seat was measured by a load cell.

RESULTS

The values of different responses measured during the experiment are summarized in Tables 3 and 4 for males and females, respectively. The various male and female responses were statistically compared using a t-test. The results of most relevant comparisons are discussed below and summarized in subsequent tables.

Individual and team isometric back strengths

Table 5 shows the various back strength comparisons. Males, as expected, had significantly higher back strength than females (average 55.38 kg for males versus average 36.22 kg for females). Males also exerted more force in teams than females (average 149.07 kg for male teams versus average 91.22 kg for female teams). Furthermore, in teams, both males and females exerted more than 2.5 times more force than individual exertions. The back strengths of both males and females were significantly lower than the weight of the steel manhole cover (80.36 kg). The average team back strengths of both males and females, however, were higher than the weight of the steel manhole cover. The average back strength of females

Table 3. Summary of response measurements for males (20 individuals and 10 2-member teams).

Response	Mean	Std. Deviation	Range
Individual MAWL (kg)	33.83	6.21	21.33-49.48
Individual RPE	13.05	1.10	12.00-16.00
Individual spinal compression (N)	5081	1059	2897-7815
Team MAWL (kg)	76.04	17.49	54.48-108.50
MAWL shorter member (kg)	39.17	7.99	27.05-53.89
MAWL taller member (kg)	36.86	9.16	27.42-54.89
Team RPE	12.40	1.53	7.00-14.00
Spinal compression for team lifting (N)			
Shorter member	6090	1599	3958-8704
Taller member	5608	1396	3895-8581
Individual RPE for lifting MAWL 5 times	14.60	1.57	12.00-17.00
Individual heart rate for lifting MAWL 5 times	122.30	16.41	96.00-170.00
Team RPE for lifting team MAWL 5 times	13.45	1.28	10.00-15.00
Average team heart rate for lifting team			
MAWL 5 times	116.65	13.03	92.00-150.00
Individual RPE for lifting 38.13 kg once (N=4)	12.50	1.00	11.00-13.00
Team RPE for lifting 38.13 kg once	8.95	1.79	6.00-11.00
Individual RPE for lifting 38.13 kg			
5 times (N=4)	12.75	1.26	.00-14.00
Heart rate for lifting 38.13 kg 5 times,			
individually (N=4)	127.50	25.59	102.00-163.00
Team RPE for lifting 38.13 kg 5 times	9.75	1.99	6.00-12.00
Average team heart rate for lifting 38.13 kg			
5 times	106.95	13.79	83.00-144.00
RPE for removing composite cover with the handle			
once (individually)	10.25	.86	6.00-12.00
RPE for removing composite cover with the handle			
5 times (individually)	10.75	2.36	6.00-15.00
Heart rate for removing composite cover with			
the handle 5 times (individually)	107.10	14.56	80.00-134.00

Table 4. Summary of response measurements for females (20 individuals and 10 2-member teams).

Response	Mean	Std. Deviation	Range
Individual MAWL (kg)	25.29	4.99	19.52-36.77
Individual RPE	13.35	0.99	11.00-16.00
Individual spinal compression (N)	3592	851	2580-5594
Team MAWL (kg)	59.56	6.84	48.12-72.64
MAWL shorter member	31.01	3.59	21.92-38.53
MAWL taller member	28.54	3.20	21.02-34.10
Team RPE	12.85	1.63	11.00-17.00
Spinal compression for team lifting (N)			
Shorter member	4586	627	3745-5899
Taller member	4154	559	2997-5125
Individual RPE for lifting MAWL 5 times	14.50	2.11	8.00-17.00
Individual heart rate for lifting MAWL 5 times	120.90	16.13	86.00-158.00
Team RPE for lifting team MAWL 5 times	13.20	1.88	11.00-18.00
Average team heart rate for lifting team			
MAWL 5 times	109.10	12.95	80.00-136.00
Team RPE for lifting 38.13 kg once	9.00	1.72	7.00-13.00
Team RPE for lifting 38.13 kg 5 times	9.75	1.97	8.00-15.00
Average team heart rate for lifting 38.13 kg			
5 times	102.80	12.21	72.00-123.00
RPE for removing composite cover with the handle			
once (individually)	10.00	1.59	8.00-14.00
RPE for removing composite cover with the handle			
5 times (individually)	11.90	1.55	10.00-17.00
Heart rate for removing composite cover with			
the handle 5 times (individually)	120.40	14.75	92.00-149.00

Table 5. Summary of comparisons (t-test) between and within male and female isometric back strengths.

Difference tested	Significance level	Inference
Individual male back strength - individual female back strength	< 1%	Males are stronger than females
Male team back strength - female team back strength	< 1%	Male teams are stronger than female teams
Male team back strength - individual male back strength	< 1%	Males in teams of two are stronger than individual males
Female team back strength - individual female back strength	< 1%	Females in teams of two are stronger than individual females

was also lower than the weight of the composite manhole cover, but higher than the vertical force exerted when removing the composite manhole cover with the handle (21.34 kg).

Individual and team psychophysical lifting capacity (MAWL)

Males, on the average, accepted 33.83 kg weight for lifting in the manhole cover size container compared to 25.29 kg weight accepted by females for lifting in the same container. As in the case of isometric back strength, both male and female teams had much higher MAWLs than individual MAWLs (Table 6). Male teams also had a significantly higher MAWL than female teams (average 76.04 kg for male teams versus average 59.56 kg for female teams). In male teams, the shorter member lifted approximately 6% more weight than the taller member. Shorter member in the female teams lifted approximately 8% more weight than the taller member of the team. The differences in the weight lifted by team members were significant ($p < .01$). Both individual and team MAWLs for males and females were lower than the weight of the steel manhole cover (80.36 kg). While the team MAWLs of males and females were higher than the weight of the composite manhole cover (38.13 kg), their average individual MAWLs were not (only 4 males had an MAWL exceeding 38.13 kg). The average individual MAWLs of both males and females, however, were higher than the vertical force exerted in removing the composite manhole cover with the help of the handle (21.34 kg). The comparisons of various MAWLs are shown in Table 6.

Spinal compression during individual and team lifting

The spinal compressive forces resulting from manual lifting were estimated from the 3-dimensional dynamic biomechanical model developed by Kromodihardjo and Mital (1986, 1987). Tables 3 and 4 show these forces for individual and team MAWL for males and females, respectively. The average spinal compressive force at MAWL for males lifting individually was 5081 N. For females, the average spinal compressive force at individual MAWL was 3592 N. When lifting MAWL in teams of two, the compressive forces were significantly higher ($p < 0.01$) for shorter members of the team than compressive forces for the taller members of the team (average 6090 N for the shorter member of the male teams and 5608 N for the taller member of the male teams versus average 4586 N for the shorter member of the female teams and 4154 N for the taller member of the female teams). The spinal compressions for both members of the team, however, were significantly higher than spinal compressive forces for individual lifting ($p < 0.01$). This was true for both males and females. Thus, the individuals were subjected to greater spinal stress when lifting

in teams of two than when lifting alone. The spinal compressive force when removing the composite manhole cover with the handle (vertical force 21.34 kg) was 2898 N. The average spinal compressive force was slightly smaller (2501 N) when the composite manhole cover weight (38.13 kg) was lifted by two-person teams. The results of various comparisons are tabulated in Table 7.

Table 6. Summary of comparisons (t-test) between and within male and female MAWLs.

Difference tested	Significance level	Inference
1. Individual male MAWL - individual female MAWL	< 1%	Males accept heavier weights for lifting than females
2. Male team MAWL - female team MAWL	< 1%	Male teams accept heavier weights than female teams
3. Male team MAWL individual male MAWL	< 1%	Male teams accept heavier weights than individual males
4. Female team MAWL - individual female MAWL	< 1%	Female teams accept heavier weights than individual females

Table 7. Summary of comparisons (t-test) between and within male and female spinal compressive forces.

Difference tested	Significance level	Inference
1. Male spinal compressive force when lifting MAWL individually - female spinal compressive force when lifting MAWL individually	< 1%	Higher spinal stresses are imposed on males when lifting MAWL than females
2. Average male spinal compressive force when when lifting team MAWL - average female spinal compressive force when lifting team MAWL	< 1%	Individual male members are subjected to greater spinal stresses in team lifting than individual female team members
3. Average male spinal compressive force when lifting team MAWL - male spinal compressive force when lifting individual MAWL	< 1%	Members are subjected to higher spinal stress when lifting team MAWL than when lifting individual MAWL
Average female spinal compressive force when lifting team MAWL - female spinal compressive force when lifting individual MAWL	< 1%	Same as above

Ratings of perceived exertion (RPE) for individual and team lifting

Tables 3 and 4 show the average RPE values for individual and team lifting for males and females, respectively. The results of various comparisons of these values are shown in Table 8. In general, females perceived all tasks to be slightly more demanding than males. The differences between males and females, however, were not significant ($p \geq 0.10$ in all cases except one). Furthermore, both males and females perceived lifting MAWL in teams to be physically as stressful as lifting MAWL alone ($p \geq 01.10$). Lifting MAWL individually 5 times was perceived to be harder than lifting MAWL 5 times in a team. For both males and females, individual and team lifting 38.13 kg (weight of the composite manhole cover) were perceived to be easier than lifting corresponding MAWLs. Team lifting 38.13 kg either once or 5 times consecutively was perceived least stressful by both males and females. Removing the composite manhole cover with the help of the handle, either once or 5 times consecutively, was perceived to be more difficult than lifting 38.13 kg in a team.

Even though the removal of composite manhole cover individually with the help of the handle was perceived to be more stressful than lifting the composite manhole cover in a team, it was considered a "light" task by both males and females. Even when the composite manhole cover was removed 5 times consecutively, the task was not perceived to be difficult.

Overall, the results show that both males and females prefer lifting the composite manhole cover, either conventionally straight up or with the handle, than lifting MAWL. This preference applies to both individual and team lifting and to lifting once or 5 times consecutively.

Table 8. Summary of comparisons (t-test) between and within male and female RPEs.

Difference tested	Significance level	Inference
1. Male RPE for individual lifting - female RPE for individual lifting	$\geq$ 10%	There was no difference in the perception of task difficulty between males and females
2. Male RPE for team lifting female RPE for team lifting	$\geq$ 10%	Male teams perceived the task difficulty to be the same as female teams
3. Male RPE for team lifting - male RPE for individual lifting	$\geq$ 10%	Male teams perceived the task difficulty to be the same as individual males
Female RPE for team lifting - female RPE for individual lifting	$\geq$ 10%	Same as above
4. Individual male RPE for lifting MAWL 5 times - individual female RPE for lifting MAWL 5 times	$\geq$ 10%	Males and females perceived lifting MAWL 5 times to be equally difficult
5. Male team RPE for lifting MAWL 5 times - female team RPE for lifting MAWL 5 times	$\geq$ 10%	Same as above for teams
6. Male team RPE for lifting 38.13 kg once - female team RPE for lifting 38.13 kg once	$\geq$ 10%	Same as above
7. Male team RPE for lifting 38.13 kg 5 times - female team RPE for lifting 38.13 kg 5 times	$\geq$ 10%	Same as above
8. Male RPE for removing composite cover with the handle once - female RPE for removing composite cover with the handle once	$\geq$ 10%	Same as above
9. Male RPE for removing composite cover with the handle 5 times - female RPE for removing composite cover with the handle 5 times	$\geq$ 7%	Same as above
10. Individual male RPE for lifting MAWL 5 times - individual male RPE for lifting MAWL once	< 1%	The exertion of lifting MAWL 5 times was perceived to be more difficult than lifting MAWL once
Individual female RPE for lifting MAWL 5 times - individual female RPE for lifting MAWL once	< 6%	The exertion of lifting MAWL 5 times was perceived to be more difficult than lifting MAWL once
11. Individual male RPE for lifting MAWL once - male team RPE for lifting MAWL 5 times	$\geq$ 10%	Lifting MAWL once individually was perceived to be as difficult as lifting MAWL in a team 5 times
Individual female RPE for lifting MAWL	$\geq$ 10%	Same as above

once - female team RPE for lifting MAWL 5 times		
12. Male team RPE for lifting 38.13 kg once - individual male RPE for lifting MAWL once	< 1%	Lifting 38.13 kg in a team was perceived to be far easier than lifting MAWL individually once
Female team RPE for lifting 38.13 kg once - individual female RPE for lifting MAWL once	< 1%	Same as above
13. Male team RPE for lifting 38.13 kg 5 times - individual male RPE for lifting MAWL once	< 1%	Lifting 38.13 kg in a team 5 times was perceived to be far easier than lifting MAWL individually once
Female team RPE for lifting 38.13 kg 5 times - individual female RPE for lifting MAWL once	< 1%	Same as above
14. Individual male RPE for removing composite cover with the rod once - individual male RPE for lifting MAWL once	< 1%	Removing the composite cover with the handle once was perceived to be easier than lifting MAWL individually once
Individual female RPE for removing composite cover with the handle once - individual female RPE for lifting MAWL once	< 1%	Same as above
15. Individual male RPE for removing composite cover with the handle 5 times - individual male RPE for lifting MAWL once	< 1%	Removing composite cover with the handle 5 times was perceived to be much easier than lifting MAWL individually once
Individual female RPE for removing composite cover with the handle 5 times - individual female RPE for lifting MAWL once	< 1%	Same as above
16. Individual male RPE for lifting 38.13 kg once - individual male RPE for lifting 38.13 kg 5 times	$\geq$ 10%	Lifting 38.13 kg once and 5 times were perceived to be equally difficult
17. Male team RPE for lifting 38.13 kg once - male team RPE for lifting 38.13 kg 5 times	< 1%	Lifting 38.13 kg in a team once was much easier than lifting the same weight in a team 5 times
Female team RPE for lifting 38.13 kg once - female team RPE for lifting 38.13 kg 5 times	< 1%	Same as above
18. Individual male RPE for lifting 38.13 kg once - individual male RPE for removing composite cover with the handle once	< 4%	Removing the composite cover with the handle was perceived to be much easier than lifting it conventionally (straight up)
19. Individual male RPE for lifting 38.13 kg once - individual male RPE for removing composite cover with the handle 5 times	< 5%	Removing composite cover with the handle 5 times was perceived to be easier than lifting the cover once, conventionally
20. Male team RPE for lifting 38.13 kg once - individual male RPE for removing composite	< 2%	Lifting 38.13 kg in a team is easier than removing the composite cover with the

cover with the handle once		the handle
Female team RPE for lifting 38.13 kg once - individual female RPE for removing composite cover with the handle once	< 2%	Same as above
21. Male team RPE for lifting 38.13 kg once - individual male RPE for removing composite cover with the handle 5 times	< 1%	Same as above
Female team RPE for lifting 38.13 kg once - individual female RPE for removing composite cover with the handle 5 times	< 1%	Same as above
22. Individual male RPE for lifting 38.13 kg 5 times - individual male RPE for removing the composite cover with the handle 5 times	< 7%	It is easier to remove the composite cover with the help of the handle than to lift it conventionally
23. Male team RPE for lifting 38.13 kg 5 times - individual male RPE for removing the composite cover with the handle 5 times	< 5%	Team lifting the composite cover repetitively is perceived to be easier than removing the cover with the handle individually
Female team RPE for lifting 38.13 kg 5 times - individual female RPE for removing the composite cover with the handle 5 times	< 1%	Same as above
24. Male RPE for removing the composite cover with the handle once - male RPE for removing the composite cover with the handle 5 times	$\geq$ 10%	Removing the composite cover with the handle once or several times is perceived by males to be equally demanding
Female RPE for removing the composite cover with the handle once - female RPE for removing the composite cover with the handle 5 times	> 1%	Females perceive removing the composite cover once to be less stressful than removing the cover with the handle 5 times

Heart rates during individual and team lifting

Table 9 shows the various comparisons. The average heart rates during team lifting were significantly lower than during individual lifting for both males and females. The average heart rates of both males and females were least when lifting 38.13 kg conventionally in a team (Tables 3 and 4) While for males, removing the composite manhole cover with the handle was physiologically as demanding as lifting it conventionally in a team, females found team lifting the composite manhole cover much easier than removing it with the help of the handle. Since only males were able to lift the composite manhole cover alone conventionally, we compared their average heart rate when removing the composite manhole cover conventionally with the average heart rate when removing the composite manhole cover with the handle. Removal of the composite manhole cover with the handle was physiologically far less demanding than lifting it alone, conventionally (average heart rate of approximately 107 bpm when using the handle versus average heart rate of approximately 127 bpm when lifting conventionally).

Overall, the differences in average heart rate between males and females, even when statistically significant, were of little practical consequence. The only exception was removal of the composite manhole cover with the handle; females had a much higher heart rate than males (approximately 120 bpm on the average for females versus 107 bpm on the average for males)

Table 9. Summary of comparisons (t-test) between and within male and female heart rates.

Difference test	Significance level	Inference
1. Average male heart rate for lifting individual MAWL 5 times - average female heart rate for lifting individual MAWL 5 times	$\geq$ 10%	Males and females heart rates for lifting individual MAWL are similar
2. Average male team heart rate for lifting team MAWL 5 times - average female team heart rate for lifting team MAWL 5 times	$\geq$ 10%	Members of male and female teams have similar heart rates when lifting team MAWL
3. Average male team heart rate for lifting 38.13 kg 5 times - average female heart rate for lifting 38.13 kg 5 times	$\geq$ 10%	Same as above
4. Average male heart rate for removing composite cover with handle 5 times - average female heart rate for removing composite cover with handle 5 times	< 1%	The physiological cost of removing composite cover with the handle 5 times was greater for females than males
5. Average male heart rate for lifting individual MAWL 5 times - average male team heart rate for lifting team MAWL 5 times	< 4%	Team lifting is physiologically less demanding than individual lifting
Average female heart rate for lifting individual MAWL 5 times - average female team heart rate for lifting team MAWL 5 times	< 1%	Same as above
6. Average male heart rate for lifting individual MAWL 5 times - average male heart rate for lifting 38.13 kg 5 times	$\geq$ 10%	Lifting MAWL 5 times was physiologically the same as lifting 38.13 kg 5 times
7. Average male heart rate for lifting individual MAWL 5 times - average male heart rate for removing composite cover with the handle 5 times	< 1%	Removing composite cover with the handle 5 times is physiologically less demanding than lifting MAWL 5 times
Average female heart rate for lifting individual MAWL 5 times - average female heart rate for removing composite cover with the handle 5 times	$\geq$ 10%	Removing composite cover with the handle 5 times is physiologically as demanding as lifting individual MAWL 5 times
8. Average male heart rate for lifting individual MAWL 5 times - average male team heart rate for lifting 38.13 kg 5 times	< 1%	Lifting individual MAWL 5 times is physiologically less demanding than lifting 38.13 kg 5 times in a team
Average female heart rate for lifting individual MAWL 5 times - average female team heart rate for lifting 38.13 kg 5 times	< 1%	Same as above

9. Average male team heart rate for lifting team MAWL 5 times - average male heart rate for lifting 38.13 kg individually 5 times	< 3%	Lifting team MAWL 5 times is physiologically less demanding than lifting 38.13 kg individually 5 times
10. Average male team heart rate for lifting team MAWL 5 times - average male team heart rate for lifting 38.13 kg 5 times	< 1%	Team lifting 38.13 kg 5 times is physiologically easier than team lifting team MAWL 5 times
Average female team heart rate for lifting team MAWL 5 times - average female team heart rate for lifting 38.13 kg 5 times	< 1%	Same as above
11. Average male team heart rate for lifting team MAWL 5 times - average male heart rate for removing composite cover individually 5 times	< 1%	Removing composite cover with the handle 5 times, individually, is physiologically easier than lifting team MAWL 5 times
Average female team heart rate for lifting team MAWL 5 times - average female heart rate for removing composite cover with the handle, individually, 5 times	< 1%	For females team lifting MAWL 5 times is physiologically less demanding than removing composite cover with the handle, individually, 5 times
12. Average male team heart rate for lifting 38.13 kg 5 times - average male heart rate for lifting 38.13 kg 5 times individually	< 1%	Team lifting 38.13 kg 5 times is physiologically much easier than lifting it 5 times individually
13. Average male heart rate for lifting 38.13 kg 5 times individually - average male heart rate for removing composite cover with the handle 5 times, individually	< 1%	Removing composite cover with the handle 5 times is physiologically less demanding than lifting it up individually, conventionally
14. Average male team heart rate for lifting 38.13 kg 5 times - average male heart rate for removing composite cover with the handle, individually, 5 times	$\geq$ 10%	Lifting 38.13 kg in a team 5 times is as demanding as removing composite cover individually with the handle 5 times
Average female team heart rate for lifting 38.13 kg 5 times - average female heart rate for removing composite cover with the handle, individually, 5 times	> 1%	For females, lifting 38.13 kg in a team 5 times is less demanding than removing the composite cover with the handle, individually, 5 times

DISCUSSION

The major objective of this study was to compare the traditional steel manhole cover with the newer composite manhole cover. Comparison of conventional lifting technique (lifting vertically) with the removal of composite manhole cover with a handle was also of major interest. In order to evaluate the physical stresses imposed upon individuals during removal of manhole covers and to compare the two designs, we first determined the capacity of the individuals to lift an object similar to the size of the manhole covers individually and in teams of two. The isometric back strength and psychophysical lifting capacity of individuals and teams were therefore determined.

The results indicated that average isometric back strength and average psychophysical lifting capacity of individuals (MAWL) were far lower than the weight of the steel manhole cover (80.36 kg). Furthermore, even though the team isometric strengths were higher than the weight of the steel manhole cover, the team MAWLs of both males and females were substantially lower. If the steel manhole cover is lifted alone, its weight would result in a spinal compression of approximately 13210 N (Kromodihardjo and Mital, 1986, 1987). At this compression all female and almost all male spines would be crushed (Jager and Luttmann, 1991). Even if the steel manhole cover is lifted by a team of two, the resulting spinal compression would exceed the spinal column strength of almost all females and most males (96% of females and 63% of males). The steel manhole cover, thus, is clearly unsafe for manual handling.

The composite manhole cover, which weighs 38.13 kg, can be removed in two ways: (1) by lifting it straight up (conventional way) individually or in a team and (2) by removing it with the help of the handle as shown in Figure 3. As the results in Tables 3 and 4 indicate, this weight exceeds the psychophysical lifting capacity of most males and females. In fact, only 4 males had an individual MAWL of more than 38.13 kg. None of the female MAWLs exceeded or equaled 38.13 kg. The spinal compression when lifting the composite manhole cover alone, conventionally, would be approximately 5832 N. This again would exceed the spinal column strength of the majority of females and a large proportion of males (90% females and 52% of males)

Team lifting the composite manhole cover, however, would result in a spinal compressive force of only 2501 N (average 19.065 kg weight for each team member - in fact, the shorter members will lift slightly

more than 19.065 kg and taller members slightly less than 19.065 kg). This compressive force would result in a factor of safety of approximately 36% for females and 56% for males (based on average spinal column compressive strength provided by Jager and Luttmann, 1991). The factor of safety will be slightly lower for the shorter member of the team and slightly higher for the taller member of the team. Team lifting the composite manhole cover also resulted in lowest heart rates and RPE values.

While team lifting of composite manhole cover results in least stresses and is perceived least stressful by the individuals, practical considerations frequently may not allow it. In such situations, the manhole cover must be handled by only one individual, male or female. As the average individual MAWLs of males and females are well below 38.13 kg, lifting the composite manhole cover straight up is out of the question. Since removing the composite manhole cover with a handle, as opposed to lifting it, is feasible, the physical stresses resulting from using the proposed method need to evaluated. As mentioned earlier, a vertical force of approximately 21.34 kg needs to be exerted in order to remove the composite manhole cover from its seat when using the handle. This force is slightly higher than the approximate weight each member of the team would lift when lifting the composite manhole cover in a team (19.07 kg; shorter members of the team will lift more than 19.07 kg and taller members less than 19.07 kg) The spinal compressive force when the composite manhole cover is removed by the handle is approximately 2898 N. While this spinal compression is higher than the spinal compression for team lifting, it still provides a factor of safety of approximately 26% for females and 49% for males. Furthermore, even though the vertical force is higher than that encountered in team lifting the composite manhole cover, both males and females perceive composite manhole cover removal with the handle to be "light". Thus, removal of the composite manhole cover with the help of the handle individually or conventionally in a team of two, are both acceptable methods.

CONCLUSIONS

The results of this study and the above discussion lead to the following conclusions:

1 Teams have significantly greater isometric back strength than individuals.

2. Males, individuals or teams, have significantly greater isometric back strength than females.

3. Males, individually or in teams, accept significantly heavier weights for lifting than females. On the average, males lift 33.83 kg individually while females lift 25.29 kg individually. Males in teams lift 76.04 kg compared to female teams which lift 59.56 kg.

4. The weight of the steel manhole cover (80.36 kg) is substantially more than the average team capacity of males or females. Shorter members of the team lift approximately 6% to 8% more weight than taller members of the team.

5. The steel manhole cover, if lifted individually, would impose spinal stresses (13210 N when lifting individually and approximately 6186 N when lifting in teams) that exceed the compressive strength of the spinal column of most individuals. Even if the steel manhole cover is lifted by a team of two members, the resulting spinal compressive stress would put the majority of the population at risk. The steel manhole cover, therefore, is unsafe for manual handling.

6. The composite manhole cover can be lifted safely, conventionally, by a male or a female team of two or by males and females, individually, with the help of the handle.

7. The use of handle allows removal of the composite manhole cover by a single individual, male or female. The composite manhole cover, otherwise, would have to be lifted by a team of two individuals.

8. The composite manhole cover and the recommended method of removing and replacing it (with the handle) not only reduce the physical stress individuals are subjected to during manhole cover removal significantly, they make it possible for an individual, male or female, to complete the task alone and safely.

9. The individuals lifting the composite manhole cover, either conventionally or with the handle, have a factor of safety of at least 26% for females and 49% for males.

REFERENCES

Ayoub, M.M. and Mital, A., 1989. **Manual Materials Handling**. Taylor & Francis Ltd., London, United Kingdom.

Borg, G.A.V., 1985. **An Introduction to Borg's RPE-Scale**. Movement Publications, Ithaca, New York.

Jager, M. and Luttmann, A., 1991. Compressive strength of lumbar spine elements related to age, gender, and other influencing factors. In **Electromyographical Kinesiology** (Editors: P.A. Anderson, D.J Hobart, and J.V. Danoff), Elsevier Science Publishers, pp. 291-294.

Kromodihardjo, S. and Mital, A., 1986. Kinetic analysis of manual lifting activities: part development of a three-dimensional computer model. **International Journal of Industrial Ergonomics**, 1, 77-90.

Kromodihardjo, S. and Mital, A. 1987. Biomechanical analysis of manual lifting Tasks. **Journal of Biomechanical Engineering**, 109, 132-138.

Mital, A., Nicholson, A.S., and Ayoub, M.M. 1992. **A Guide to Manual Materials Handling**. Taylor & Francis Ltd., London, United Kingdom.

Mital, A., 1984. Maximum weights of lift acceptable to male and female industrial workers for extended work shifts. **Ergonomics**, 27, 115-1126.

Appendix A

Personal Data Form

PERSONAL DATA FORM

AME _____ DATE:_____

Name and phone number of individual to be contacted in case of emergency:

_____

Age: Weight:_____ pounds) Height:_____

Are you susceptible to:

Dizziness Chronic Headaches Fatigue

Have you had or do you now have a hernia?
Corrective Date:_____

Have you ever had extreme shoulder or arm pain?_____
If so, explain_____

Have you had or do you now have a problem with your blood pressure?

_____

Have you had any type of surgery or serious illness within the past six months?_____ If so, what?_____

What is the nature of your present job? Explain_____

_____

Does it include or involve manual materials handling?_____
What kind? Explain_____

Have you performed any manual handling tasks in the past?_____
If so, what kind?_____

How long ago?_____How many hours a day?_____

Have you had your normal amount of food within the past 24 hours?

_____

Have you had your normal amount of sleep within the past 24 hours?

_____

Have you ever had back pain, particularly lower back pain?_____
Are you presently suffering from any other physical ailment?
If so, what?_____

Are you presently on medication?_____
If yes, what?_____

Do you know of any reason that physical stress would cause you injury?_____

How would you rate your present physical condition? _____
Fair; _____ Good; Excellent; Poor;

Have you ever had or are you presently suffering from any heart and / or vascular disease? _____ If yes, what? _____
How long? _____

_____ Date _____
Subject's Signature

_____
Witness

Appendix

Consent Form

CONSENT FORM

I have truthfully answered the questions, to the best of my knowledge, pertaining to my personal data. I consent to participation in the experiment entitled " Evaluation of Manhole Covers". It has been explained to me that this activity is a part of a project that has its main objective : "To determine which design is superior". The data will be useful in designing products which do not cause undue physical stress while handling.

I understand that I, and only I, will determine my weight lifting capacity. During this experiment, my physiological costs (heart rate and oxygen uptake) may also be measured in order to estimate the job related fatigue. The project representatives have agreed to answer any inquiries I may have concerning the procedures.

I understand that I may discontinue my participation in this study at any time I choose. I further understand that I may not derive therapeutic treatment from participation in this study. However, the possibility of any of these taking place is remote since the experimental procedure requires that I operate within my capacity. The University of Cincinnati is not liable for any personal injury resulting from my participation in this study. The University of Cincinnati follows a policy of making all decisions concerning compensation and medical treatment for injuries occuring during or caused by participation in biomedical or behavioral research on an individual basis.

I understand that all data will be kept confidential and that my name will not be used in any reports written or unwritten.

I, the undersigned, have understood the above explanations and given consent to my voluntary participation in the project "Evaluation of Manhole Covers".

Signature of Subject _____ Date _____

Name of Subject (Print) _____

Mailing Address

_____

_____

_____

Phone Number _____

_____

(Signature of PI/PD or his authorized representative)

Date _____