



Development of tractor operated bund former-cum-packer for increasing resource productivity

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ABSTRACT

In mechanized farm, bund is prepared by a bund former either operated by tractor or animals for irrigation purposes and also to demarcate the fields. Tractor operated bund formers are normally either disc -or mould board or forming board type. If bund is formed with the help of traditional bund former, however, shaping and packing of bunds is done manually using spade and feet. This activity is time consuming and labour intensive. To overcome the drudgery involve in these operations, a tractor operated bund former-cum-packer was designed and developed. An attempt is made for enabling the combined operations of bund forming and packing in single pass that can save fuel, time and other resources further. The bund former-cum-packer consisted of commercially available disc type bund former, rectangular tool bar frame, and packing unit (concentric cylindrical roller, drive shaft, conical discs, compressive shanks etc). The bund formed by bund former-cum-packer was field tested and found neither water seepage nor breakage of bund during flood irrigation. The field capacity with the equipment was 1.4 ha/h at tractor speed of 2.93 km/h in 2nd low gear. The bund former-cum-packer can reduce about 96% dependency on labour requirement for packing the bund. Overall use of the equipment is having potential to increase the resource productivity by 38 %.

Key words: Bund former, Bund packing, Compaction, Conical disc, Irrigation channel

In mechanized farm, bund is prepared by a bund former either operated by tractor or animals. Tractor operated bund formers are normally either disc or mould board type or forming board type (Srinivasarao *et al.* 2013 and Bureau of Indian Standard 1999). The bund former is used to make bund for irrigation purposes and also for demarking the fields. Around 21 bunds could be formed in one ha area having total bund length of around 2050 m. Bund formed using bund former is packed or firmed manually with spade and human feet. This activity is time consuming and labour intensive. Normally a person can pack or firm the formed bund 100-150 m length in an hour. There is a commercially available machine in which discs are hydraulically controlled to shape the formed bund from one side. No such machine is commercially available to pack or firm the formed bund in the country. To ease the firming operation, an attempt was made to design and develop such machine which enables combined operations of bund forming and packing in single pass for saving fuel and resources.

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MATERIALS AND METHODS

The shape of bund formed in pulverised/cultivated field with bund former is triangular. After manually packing/ firming of formed bund, it becomes trapezium shaped. Following points were considered while designing the different components of bund former-cum-packer for its fabrication and further assessment: (1) Machine is to be mounted type and can be operated by a 35/45 hp (26/33 kW) tractor. (2) The sides of bund after packing should be firmed to avoid seepage. (3) Trapezium shape packer with rolling action is required to develop. (4) Forming and packing of bund simultaneously will ease the tractor operator and its smooth operation. (5) The weight of packing unit should be sufficient to compress the top of bund up to 70-100 mm for getting height of packed bund up to 250 mm. (6) The distance between packing unit and forming unit is to be kept as much as that sufficient soil thrown by bund former could be received by packing unit to make it combined operations. (7) Packing unit should be minimum 150 mm above the level of disc of forming unit from ground level. (8) The total length of mounted disc type bund former-cum-packer should be such that stability may not be affected in operation. (9) Forward speed of tractor is up to 2nd low gear (about 3 km/hr).

The former-cum-packer consists of commercially available disc type bund former, rectangular tool bar frame, and packing unit (concentric cylindrical roller, drive shaft,

conical disc, compressive shanks etc). Under the following sections, the different aspects related to design of different components of packing unit and rectangular tool bar frame are briefly described.

To decide the weight of bund packer, a tension and compression type load cell was used to assess the compressive force required for compacting soil from top of bund prepared by tractor operated disc type bund former. The force requirement was observed to be 1.1 N/cm² (392.4 N/364 cm² in reducing the height up to 7 cm). The area of manually compacted bund was found to be 1 274 cm². Therefore, weight of bund packer could be [(1 274 × 1.1)/9.81] 142.9 kg.

Volume of soil worked with bund packer/m length was taken as criteria for assessment of work done by a bund packer,

$$\begin{aligned} &= \text{triangular area} \times \text{length} \\ &= (\frac{1}{2} \times 48 \times 80) \times 100 \\ &= 192\ 000 \text{ cc} \end{aligned}$$

$$\begin{aligned} \text{Weight of soil/m} &= \text{density} \times \text{volume of soil} \\ &= 1.256 \times 192\ 000/1\ 000 = 241.145 \text{ kg} \end{aligned}$$

$$\text{Power (kW)} = \text{Torque} \times \text{rpm} / 9550 \quad (\text{Krutz } et al. 1984)$$

Considering weight of soil to be compacted by bund packer in one meter as Torque,

$$T = 241.145 \times 9.81 = 2\ 365.6 \text{ N-m}$$

$$\text{RPM} = 56$$

$$\text{Power} = 13.87 \text{ kW}$$

Considering coefficient of traction of cultivated soil as 0.55 (FAO 1994), the potential power requirement would be 25.22 kW (≈35hp).

Design of axle shaft was done considering torsion combined with bending and assuming uniformly distributed load on simple supporting beam. Following formula was used for calculating diameter of cylinder shaft:

$$\frac{\pi d^3}{16} = \frac{\sqrt{T^2 + M^2}}{S_{allow}}$$

where, d = diameter of cylinder shaft, cm; T = torque on shaft, kg-cm; M = bending moment on shaft, kg-cm; S_{allow} = allowable stress for mild steel shaft, 560 kg/cm².

Torque on cylinder shaft was calculated using following formula.

$$T = \frac{HP \times 4500}{2\pi N}$$

where, HP = horse power to be transmitted (the drawbar horse power of 35 hp = 0.72 × 35 = 25.2); N = speed of shaft (56 rpm); π = 3.14.

Thus,

$$T = \frac{25.2 \times 4500}{2 \times 3.14 \times 56N} = 322.45 \text{ kg-m} = 32\ 245 \text{ kg-cm}$$

Bending moment was calculated assuming uniformly distributed load over a simply supported beam.

Load was calculated based on weight of soil to be handled for packing of bund in one revolution, which is 81.2 kg [considering peripheral diameter of (spool-axle

shaft) × 230 × 550]. In one metre length, no. of revolutions of conical disc will be 0.65. The factor of safety is taken as 2. Bending moment on cylinder shaft was calculated by:

$$M = \frac{W \times l}{4}$$

where, M = bending moment, kg-m; W = load per metre length, kg/m; = 241.145, l = length of bund = 1.0 m.

$$M = \frac{241.145 \times 1^2}{4} = 60.3 \text{ kg-m} \approx 6030 \text{ kg-cm}$$

Putting the value of torque, bending moment and allowable shearing stress,

$$\begin{aligned} \frac{\pi d^3}{16} &= \frac{\sqrt{(32245)^2 + (6030)^2}}{560} \\ d &= 6.68 \text{ cm} = \text{Say } 67 \text{ mm} \end{aligned}$$

PTO hp is usually about 85% of engine horsepower and drawbar hp is about 85% of PTO hp, Barger *et al.* (1967). So, a tractor of 100 engine hp will generate approx. 85 pto hp and approx. 72 drawbar hp. Variables include hydraulic and electrical load, type of transmission, speed, ballast, soil conditions etc.

The conical discs are supported at both ends with bearings. Empirical formula is adopted for the design of shaft in terms of hp transmitted and the speed of shaft rotation in rpm.

$$\begin{aligned} \text{Power to be transmitted} &= \text{dbhp of 35hp tractor} = 26\text{hp} \\ \text{RPM} &= 56 \end{aligned}$$

$$d = (\text{H.P} \times c/\text{RPM})^{1/3} \quad (\text{Singh } 1991)$$

where, c = constant (= 810 for transmission shaft subjected to torsion only), d = shaft diameter, cm.

So,

$$d = (26 \times 810/56)^{1/3} = 7.22 \text{ cm}$$

Bearing housing and spool diameter was 100 and 170 mm, respectively so, diameter of hollow shaft was taken 64 mm because majority of load while packing bund is observed to be shared by spool and bearing housing.

The diameter of cylindrical roller was selected as 170 mm, in such a way that its diameter might be slightly higher to make it easy in roll and not to drag the soil. Length of roller was as per size of manual compacted bund which is 230 mm. Hollow cylindrical roller was opted to make it concentric as main axle will pass through it.

Considering the requirement of manual packed bund, the disc was designed in such a way that the loose bund formed by bund former may be packed from top as well as from both sides. The diameter, slanted length, concavity and bottom width of bund were determined as 490, 188, 153 and 550 mm, respectively. The thickness of conical disc was calculated as per following empirical formula.

$$\begin{aligned} \text{Thickness} &= 0.008D \quad (\text{Bosoi } et al. 1990) \\ &= 3.92 \text{ mm} \end{aligned}$$

Due to non-availability of these designed discs, the conical disc was fabricated by making a conical frame using eight mild steel (low carbon) bars of 12 mm diameter and 188 mm length as spokes at equidistance on small (170 mm

and large rings (485 mm). A 1.6 mm mild steel sheet was wrapped over it.

Tool bar is considered a simple supported beam due to its support on conical disc while mounted with three point hitch.

- Number of side arm = 2
- Maximum depth of operation = 155 mm
- Width of conical disc = 550 mm
- Clearance of tool bar and side arm = 460 mm
- Length of tool bar = 1220 mm

Bund packing cross section area by conical disc on side arm

$$= 550 \times 155 = 96\,250 \text{ mm}^2$$

Draft (N) required by side arm

$$= \text{bund packing cross-section area, mm}^2 \times \text{draftability, N/mm}^2$$

Bund packing cross section area by conical disc on side arm =

$$= 550 \times 155 = 96\,250 \text{ mm}^2$$

Draft (N) required by side arm

$$= \text{bund packing cross-section area, mm}^2 \times \text{draftability, N/mm}^2$$

$$= 96\,250 \times 0.02 = 1\,925 \text{ N}$$

$$\text{Design draft for tool bar} = \text{draft} \times \text{factor of safety} \\ = 1\,925 \times 2 = 3\,850 \text{ N}$$

Torque on tool bar by side arms

$$= \text{draft required by side arm} \times \text{ground clearance}$$

$$= 3\,850 \times 0.46 = 1\,771 \text{ N-m}$$

In addition to torque on tool bar, bending moment would also be acting on simple supported beam. Maximum bending moment will be

$$= \text{total weight / force on the tool bar} \times \text{total length of tool bar}$$

$$= 1\,771 \times 1.22 = 2\,160.62 \text{ N-m}$$

$$\text{Equivalent torque (Te)} = \sqrt{M^2 + T^2} = \sqrt{2160.62^2 + 1771^2} = 2793.7 \text{ N-m}$$

$$\text{Shear stress (Ultimate stress of selected material } 360 \text{ N/mm}^2) / R (d/2) = \text{Te} (2793.7 \times 1000) / J [1/12(B^4 - 0.857B^4) = 0.0119 B^4]$$

$$\text{Square hollow section (B}_o) = 68.83 \text{ mm}$$

Hence, square section of 75 x 75 was taken.

Total force for both shank = weight of soil per rotation of bund packer

$$= 1.54 \times 241.145 + \text{weight of equipment (142.9 kg)}$$

$$= 514.3 \text{ kg}$$

Load at one shank is assumed to be half due to simply supported beam at two places. So,

$$\text{Force} = 0.5 \times 514.3 = 257.2 \text{ kg} = 2523.13 \text{ N}$$

$$\text{Bending load} = \text{force} \times \text{factor of safety (4)} = 10092.528 \text{ N}$$

$$\text{BM max} = 460 \times 10092.528 = 4642562.9 \text{ N-mm}$$

$$Z = M / \text{stress} = 4642562.9 / (320/4 \text{ factor of safety} = 80 \text{ N/mm}^2) = 58032.1$$

$$Z = 3.14 \times d_o^4 - d_i^4 / 64$$

$$\text{So, } D_o = 45.2 \text{ mm} \quad D_i = 41.6 \text{ mm}$$

Hence, 50 mm hollow pipe was selected for each shank which is mounted to bearing housing and tool bar frame.



Fig 1 Operation of bund former-cum-packer in field

As per the design, prototype of bund former-cum-packer was fabricated and the specifications of final prototype of tractor-operated disc type bund former-cum-packer are given in Table 1.

The field evaluation of developed machine was conducted in divisional as well as IARI farm in sandy loam soil (Fig 1). The speed of operation, soil moisture content, bulk density of formed and packed bund, size of bund etc

Table 1 Specifications of tractor operated bund former-cum-packer

Particulars	Specifications
Weight of bund packer (excluding weight of bund former), kg	156
Total weight of 26 inch disc bund former-cum-packer, kg	253
Size of rectangular frame, mm	2100 × 1460
Cross-section of square hallow section for rectangular frame, mm	75 × 75
Mounting height of bund packer in rectangular frame, mm	100 above the ground
Length of compressive shanks, mm	547
Number of compressive shank	2
Diameter of concentric cylindrical roller, mm	170
Length of concentric cylindrical roller, mm	230
Diameter of main hollow axle, mm	63
Length of main hollow axle, mm	995
Diameter of conical disc, mm	525
Conical disc concavity, mm	170
Number of conical discs	2
Three-point hitch mounting pin	Category-II
Two ball bearing	6305
Size of bearing housing of a harrow, mm	100 × 100
Diameter of metal thrust ball, mm	25

were determined using standard methodology. Shape of bund formed by disc type bund former, former-cum-packer and manually packed was determined by cutting its cross-section. Shape was drawn using chart paper by marking. A cone penetrometer was also used to get the indication of compaction of packed and formed bunds. Pond method was used to assess seepage from packed and non-packed bunds. For this, flood irrigation was provided in between two channels formed and packed by the developed machine for observing the seepage during 24 h.

RESULTS AND DISCUSSION

Preliminary trial

First prototype of disc type bund packer was fabricated as per the design. It was observed during preliminary trial that there was need to have more compaction. To overcome the observation, dead load was kept over it and found more compact packed bund. Thus, it was decided to make compressive shanks using compression coil spring in place of rigid shank to obtain about 5 cm more compaction from top with developed packer. Thus, a compressive shank was designed.

Another significant observation during preliminary testing of bund packer with compressive shanks in the field was to have a combined unit of bund former and packer. This observation was due to some distortion on packing of bund and side thrust on tractor during packing operation of formed bund with bund packer only. To combine the field

operations of forming and packing of bunds simultaneously, a rectangular tool-bar frame of differential height for bund forming and bund packing operations was designed. The width of rectangular tool bar frame was kept in such a way that conical disc of bund packer starts packing of bund just after soil thrown by the bund former during bund formation. Thus, distance between disc of bund former and bund packer is kept about 450 mm. Final prototype of bund former-cum-packer was fabricated as per design and preliminary trial showed satisfactory packing of bund in continuation to its forming.

Performance evaluation

The performance evaluation of tractor operated disc type bund former-cum-packer was conducted in year 2015 and 2016 at divisional as well as IARI farm (Table 2). Increasing the tractor forward speed from 2nd low to 3rd low gear, it was observed that less compaction occurred from side as well as top. This was due to more bumping action in higher forward speed. Therefore, the bund former-cum-packer was operated in the pulverised fields at speed of 2.85-2.93 km/h (2nd low gear) while only bund former was operated at speed of 3.95 km/h. The capacity of forming bund per min was 66 m with bund former for triangular shaped non-packed bunds while it was 48 m with developed machine for trapezium shaped packed bund.

The soil moisture content varied from 6.95 to 10.37% during different experiments as normally bund is formed after pulverising the field. The bulk density of manually

Table 2 Performance of bund forming and packing

Particulars	Average values				
	Bund former	Manual packed bund	Bund former cum packer		
			2015	2015	2016
Field	ZRC	ZRC	ZRC	Divisional farm	IARI farm
Type of soil	Sandy loam				
Soil moisture content, % db	6.95	7.35	7.07	10.37	9.13
Bulk density of bund, g/cc	1.256	1.286	1.274	1.281	1.279
Deflection in cone penetrometer having cone area of 3.14 cm ² from top, mm	150- 175	25- 50	25- 50	25- 50	25- 50
Deflection in cone penetrometer having cone area of 3.14 cm ² from side, mm	100-150	25	5	3	7
Size of bund, mm	NA	250	250		
Top width	800	660	560-580		
Bottom width	480	280	210		
Height					
Shape of packed bund	Triangular	Trapezium	Trapezium		
Speed of operation, km/h	3.95	0.08-0.12	2.85	2.93	2.90
Capacity, m length/min	66	1.3-2.0	47	48	47
Output with manual packing per person, m length/day (8h)	NA	816	NA	NA	NA
Manual labour saving in compaction on length basis, %	NA	NA	96.3	96.4	96.3
Water holding capacity	Broken and seepage at some places	No breakage with Seepage at some places	No breakage of bund.No seepage.		

Table 3 Fabrication cost of tractor operated bund former-cum-packer

Particulars	Weight, kg	Approximate cost, ₹
Square frame	56.7	3402
Three point hitch category-II	26	1430
Compressive shanks	34	2210
Main hollow axle	7	700
Cylindrical roller	8.3	581
Conical discs	20	1200
Nut-bolts, 16 no.		400
Ball bearings, 2 no.		400
Miscellaneous items		200
Commercially available assembly for 680mm disc type bund former	97	19400
Total cost of material (a)		29923
Manufacturing cost	0.5 of a	14962
Profit	0.2 of a	5985
Total manufacturing cost		50870

packed bund (formed by bund former) was found highest (1.286 g/cc) compaction from top of bund, whereas it was lowest (1.256 g/cc) in the bund formed by bund former after a day.

A cone penetrometer was used to get clear-cut advantage of bund former-cum-packer in forming and packing the bund as spillage is normally from top of bund while seepage occurs from side walls during flood irrigation. From Table 2, it is clear that the deflection of dial gauge in cone penetrometer showed almost similar behaviour (25-50 mm depth) in manually as well as machine packed bund while there was very less compaction (150-175 mm depth) in a bund formed by bund former. In case of side walls, the deflection in dial gauge of cone penetrometer was observed in side walls of packed bunds with developed bund former-cum-packer at 3-7 mm depth followed by manually packed bunds at 25 mm, whereas it was least at 100-150 mm in non-packed bund. The conical disc used in packing unit compressed more soil to be packed from side as compared to its concentric roller, responsible for compaction from top of bund. This clearly indicates that the more soil penetration resistance was observed with packing of bund formed by developed machine as compared to non-packed bund. Many researchers also found a better mechanism (cone penetrometer) to know compaction level of bunds (Moraes *et al.* 2014, Kormanek *et al.* 2015 and Bo *et al.* 2016).

No seepage and spillage was observed in ponding method of irrigation with bunds packed by developed bund former-cum-packer as compared to other methods of bund formation. This is also in line to the need stressed by Michael (2009).

The above results clearly suggests in favour of packing of bund either manually or packer (machine) to avoid seepage as well as spillage. The developed machine is found to reduce the labour requirement by about 96% compared to

manually packing of bund, which indicates minimal dependence on labour for getting the timeliness in bund forming operation. The fabrication cost of bund former-cum-packer was calculated as per Singh *et al.* (2012) and it was found to be ₹ 50 870 (Table 3). Based on estimates, about total length of bund in a hectare area, the output with bund former-cum-packer comes to 1.4 ha/h as compared to 1.93 ha/h with bund former. But, the resource productivity with bund former-cum-packer was found to increase by about 38% as compared to the output of bund former with manual packing.

It can be concluded that the developed bund former-cum-packer is suitable for making and packing the bund simultaneously in the cultivated/pulverised field. The fabrication cost of the equipment was worked out to ₹ 50 870. The field capacity with the equipment was 1.4 ha/h at tractor speed of 2.93 km/h in 2nd low gear. The bund former-cum-packer can reduce about 96% dependency of farmers on manual labour requirement for packing the bund. Overall use of the equipment is having potential to increase the resource productivity by 38%.

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